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Research on Conditioning and Storage

of Rough and Milled Rice

A Review through 1958

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UNITED STATES DEPARTMENT OF AGRICULTURE

PREFACE

This report is a review through 1958 of work done in the U. S. Department of Agriculture and the Agricultural Experiment Stations of Arkansas, California, Louisiana, and Texas. The information herein has been assembled from published and unpublished sources. The research findings were made by workers in the agricultural experiment stations of these principal rice-producing States and the research Services of the U. S. Department of Agriculture having responsibility for research in the fields of drying and storing rice and preserving its quality.

The editor wishes to acknowledge with gratitude the wholehearted cooperation and valuable suggestions made during the planning and preparation of this report by the Directors and staff members of the Arkansas, California, Louisiana, and Texas Agricultural Experiment Stations and by the Directors and staffs of research divisions in the Agricultural Research Service, Agricultural Marketing Service, and Farmer Cooperative Service of the U. S. Department of Agriculture (listed in Appendix A, at end of this report).

A very special word of appreciation for his counsel and inspiration is due Dr. R. D. Lewis, Director, Texas Agricultural Experiment Station; Administrative Advisor to the Rice Technical Working Group; and a member of the Rice Research and Marketing Advisory Committee.

W. C. DACHTLER, Editor

Prepared by: Agricultural Research Service, in cooperation with Agricultural Marketing Service and Farmer Cooperative Service, USDA, and Arkansas, California, Louisiana, and Texas State Agricultural Experiment Stations.

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SUMMARY

Almost all of the rice produced in the United States is now harvested by combine, at moisture contents too high for safe handling and storage unless it is conditioned by circulation of atmospheric air or dried artificially. Compared with the product which resulted from the binder-thresher method of harvesting involving a period of field drying prior to further handling and storage, today's rice at harvesttime is a very different product. New methods, procedures, equipment, and facilities are required to maintain its quality. To successfully adjust practices to the changed conditions has required extensive research efforts both on the part of industry and governmental groups. This report summarizes information resulting from studies by State and Federal agencies during recent years, the work now underway, and the areas of investigation in which expanded or new studies may be feasible. Four State agricultural experiment stations and eight research divisions of the U. S. Department of Agriculture are devoting a part of their resources to assist the rice industry in the solution of problems associated with the maintenance of rice quality during conditioning and storage.

In the development and adaptation of new and improved methods, equipment, and facilities, the skills of many branches of science are needed. The ability to supply rice with qualities acceptable to users requires the cooperation and coordinated effort of the agronomist, chemist, economist, engineer, entomologist, microbiologist, nutritionist, and physicist. The interrelationship among these sciences is apparent throughout this report.

The varieties of rice grown in the United States differ in their reaction to handling, conditioning, and storage treatments. These variations in response often are predictable and may be explained if there is adequate information on the agronomic characteristics of the rice, its chemical composition, and its physical structure and properties. The first five sections of this report briefly review research in these areas. A great deal of information is available concerning varietal differences in rice, and plant breeders are becoming increasingly aware of the need to give more consideration in developing new varieties that possess those characteristics which will more adequately meet conditioning and storage requirements. Environmental and cultural practices during the growing season as well as the field handling and harvesting methods also have a considerable effect on the quality of the rough rice available to the drying and storage operator. Differences in moisture content, size of kernel, percentage of weed seeds and other foreign material, and hulled and broken grains make these processes more complicated and costly. An understanding of the kernel structure of rice not only is basic to the interpretation and evaluation of results obtained from the application of the different methods and practices used in conditioning and storing rice but also may point the way to new approaches to the solution of the problems. Compositional changes in rice during drying and storage result from differences in time, moisture, and temperature. These changes have pronounced effects on the cooking characteristics of rice and its acceptability to the user. There is need for more information about the composition of and changes in the major components of rice, such as starch and protein. The interrelationship of the minor constituents of rice has not been explored adequately. Studies of the physical properties of rice, particularly the humidity and temperature relationships under which rice gains or loses moisture, are fundamental to the development of efficient drying methods. Research in this area has made it possible to evolve a generally applicable law of drying. More knowledge is needed about the relative parts played in deterioration of rice by microorganisms, particularly molds and yeasts, and by enzymes native to the grain. Such information is important in determining the nature and causes of souring, stack burn, heat damage, and related storage problems. Information also is lacking on the types of organisms present under different storage conditions, the possible progressive changes in their relative amounts, and the effects of individual species or strains upon rice properties.

No single set of recommendations for conditioning rice is applicable throughout the United States. Differences in rice varieties, climatic conditions, cultural and handling practices and industry procedures require modifications in methods, equipment and facilities. Four State agricultural experiment stations and four research divisions of the USDA carry on research to develop improved methods for applying the basic principles of rice conditioning to the specific conditions encountered in each of the rice areas. Differences in the findings of these studies are noted in this report.

Heavy deliveries of rice to the drier in a short interval of time during harvest periods make it necessary to provide means for safely holding a part of the undried rice until drying facilities are available. Practical methods using aeration have been developed to prevent deterioration of undried rice for several weeks.

To dry rice, moisture must be removed from the inside of the kernel. When drying is done at too fast a rate, checking or shattering of the rice kernel often results. To reduce this effect with heated-air drying, rice usually is dried in several stages with each stage involving a pass through the drier. Between drying passes the rice is held in a storage bin until the moisture equilibrates throughout the kernels. Considerable effort has been directed to reduce the time requirements in these tempering phases without adversely affecting the quality of the rice. Further research on this problem should lead to refinements in the process.

Efficient and economical types of rice drying equipment are generally available. These are of two types--continuous-flow driers, and bin driers. There are several variations of each type which have specific advantages in meeting individual conditions. Research on drier equipment design by State and Federal agencies is now superseded by study of improved procedures and methods for their operation, to obtain greater efficiency along with high quality of product and maximum head yields when the rice is subsequently milled.

Attention has been focused more recently on methods of drying with unheated air. Unheated air drying requires less investment in equipment and usually results in more uniform drying of the rice. However, the rate of drying with unheated air depends to a considerable extent on weather conditions. The longer time required for the process as compared with drying with heated air may be a deterrent in some instances. If rice is to be held in storage for a period longer than is required for drying with unheated air, the time element is not so important. This report covers the status of information on equipment needs, air flow rates, rice depths, drying times, fan operating schedules, and related factors associated with the drying of rice by unheated air.

Following harvest and drying, rice is usually stored as rough rice in bulk storage bins. These bins may be located on the farm where the rice was produced or at commercial drier or mill. Studies have indicated no superiority or inferiority of particular materials for the construction of storage buildings. Storage structures are satisfactory if they keep the rice safe from damage from moisture, heat, and insects or other pests; and if they provide job safety and convenience in moving, inspecting, and servicing the rice. If dried rough rice is to be stored for a few months or longer or if damp rice is to be held prior to drying, the storage structure should be equipped for aeration.

Moisture content and temperature of rice control the rate of deterioration and insect infestation during storage. Turning stored rice, or transferring it from one bin to another, used to be the only way of equalizing temperature. During turning little overall cooling occurs, but the warm and cold rice are mixed, thus eliminating hot spots. As a result of research most operators now use aeration to ventilate rice and equalize the temperature of rice. Aeration avoids the expense of turning the rice, the extra bin capacity which turning requires, and possible damage to the rice from the turning operation. By use of aeration the quality of dried rough rice stored in bulk has been maintained for 5 to 8 months without turning. Recommendations for equipment and procedures based on research studies and industry experience are given in this report. Current research is directed toward refinements of the aeration process.

Insect infestation generally occurs after rice is in storage. Most rice harvested and dried by modern methods is relatively insect free upon entering storage. Practical insect control practices during storage have been developed through research and are widely applied throughout the United States. Emphasis now is being placed on developing protective treatments which will minimize the need for control methods. Materials, dosage rates, and methods of application are being evaluated. The materials which may be used for this purpose are limited by the tolerance levels for residues permissible on rice under Food and Drug Administration regulations. Further work is required to test additional protective materials for rice.

Often new methods or refinements of available methods developed through research are not wholly utilized commercially because it is believed that the additional cost of adopting the practice may be greater than the savings obtained. Unless adequate economic appraisals are made, research findings may be disregarded or followed blindly without a sound basis for the decision to use them. Only a minimum of attention has been given to the economics of the conditioning and storage of rice. Studies which have been undertaken have tended to be limited in scope and have not answered many of the problems involved.

RESEARCH ON CONDITIONING AND STORAGE OF ROUGH AND MILLED RICE

A Review Through 1958

INTRODUCTION

The shift from the binder-thresher method of harvesting rice to the use of the combine was greatly accelerated during World War II, chiefly because of the savings in labor which accompany the more highly mechanized operation. Combines which are capable of cutting, threshing, and cleaning a swath 10 to 21 feet wide at speeds from 2 to 6 miles per hour, harvest from 15 to 30 acres of rice per day. Their use has materially shortened the time required to harvest the crop when it is mature. As these machines perform more efficiently when the rice contains about 20 percent of moisture, their use also has introduced the need for drying the rice within a short time after harvest to prevent deterioration. Under the binder-thresher method rice was dried naturally in the field and was normally threshed at a moisture content of 15 percent or less.

Only fragmentary information was available by 1940 from either experience or research on efficient methods and equipment for drying and storing the rice crop under the changed conditions. During the last 20 years a substantial part of the research programs relating to rice in both the State agricultural experiment stations and the U. S. Department of Agriculture has been directed toward finding solutions to the problems of maintaining rice quality after harvest. It soon became evident that the multiplicity of approaches and the relatively limited research resources available would be more effective if there were greater coordination of effort. In 1949, therefore, a Rice Technical Committee was organized to bring together research workers from the principal rice producing States and the USDA for the purpose of exchanging and evaluating information which was being developed and to point up areas of research needing attention and emphasis. This Rice Technical Working Group, as it is now called, has served continuously to advise both the States and Federal government on the overall status and need for changes not only in the conditioning and storing of rice but in all the aspects of need which research may help to solve for the rice industry. In addition to the periodic review by the Rice Technical Working Group, the USDA rice research and marketing service program is annually appraised by a Rice Research and Marketing Advisory Committee whose membership includes representatives of rice producers, processors, distributors, and consumers. In the meetings held during December 1956, each of these advisory groups recognized the widespread activities and the considerable progress which has been made in recent years by State and Federal agencies in studies of drying, aerating, and storing rice. They recommended that research findings be assembled, analyzed, interpreted, and published in a summary report which would highlight the established principles and major applications of current knowledge on conditioning, storage, and preservation of rice. The present report is the outgrowth of their recommendations. With the perspective of such a compilation, it is hoped that a sound basis may be found for determining the need for and the planning of future research in this area. The information on which this report is based has been assembled from published and unpublished findings by research workers in the agricultural experiment stations of the principal rice producing States and the research divisions of the U. S. Department of Agriculture having responsibilities for research in the fields of drying and storing rice and preserving its quality. The organization of the material follows a master working outline prepared by a planning committee selected from these agencies. Initial summarizations were made by five specialists in the appropriate technical subject matter fields. The final format and continuity is the responsibility of the editor. A list of the individuals who had a part in the preparation of this report may be found at the end of this publication.

RELATIONSHIP OF VARIETY, ENVIRONMENT, AND CULTURAL AND FIELD HANDLING PRACTICES TO CONDITIONING AND STORING RICE

The end product of the drying and storage processes and the efficiency with which these functions are performed are dependent to a considerable extent upon the character and condition of the material which is to be dried and/or stored. The choice of variety

and quality of seed, the climatic conditions and management of the crop during the growing and harvesting periods all have pronounced effects on the operations adopted, time required, and cost in conditioning rice. These relationships are only briefly indicated in this section. A more detailed reporting is made in the sections which follow where direct effects are measurable.

Varietal Differences

Rice, like other cereals, is not a homogeneous commodity. Thousands of varieties are grown throughout the world. By comparison, the 17 or 18 commercial varieties produced in the United States seem a small number. Nevertheless they represent a wide range of field, drying, storage, and cooking characteristics. They vary in strength of straw, size and shape of grain, thickness and pubescence of hulls, uniformity of ripening, resistance to diseases and insects, optimum moisture content for harvesting, and the rate at which individual rices release moisture. In developing new varieties in recent years plant breeders have become increasingly aware of the need for more adequate consideration of the relationship of varietal characteristics to conditioning requirements and storability.

Resistance to lodging is dependent on strength of the straw. The harvested grain of erect rice usually is more uniform in moisture content and plumpness. It also tends to contain less foreign matter. Varieties with thick pubescent hulls, such as Arkrose and Zenith, are more difficult to dry than varieties which have thinner glabrous hulls, such as Bluebonnet. The size and shape of the kernel also are closely related to drying efficiency, as rices characterized by thick kernel structure release moisture more slowly (12).[1] Some varieties can withstand higher drying temperatures without significant losses in milling yields (45). Studies show, however, that there is little or no difference between varieties in their resistance to heat damage (44). Some medium-grain rices are more difficult to thresh than some of the long-grain varieties and produce more dehulled grain and fewer broken kernels (46). It has also been found that some short- and medium-grain varieties are reduced more in head yield by drying with forced heated air than are several long-grain varieties (57). Since varieties differ in moisture content when in equilibrium with the same atmosphere, their responses to drying procedures may also vary.[2] Breeding for resistance to diseases is frequently an objective in the development of new varieties but little is known as to how these differences in reaction to disease may affect conditioning and storage (2).

Environment and Cultural Practices

Rice quality varies with soil type and fertility; kind, quantity, timing, and placement of fertilizer; time of seeding; irrigation and weed control practices; weather conditions during development of the rice grains; and the use of desiccants. If rice matures uniformly with respect to time, size of kernel, and composition, the conditioning process is greatly facilitated. Fertilizer properly applied improves the quality and yield of grain, but if applied too late or in excess amount it may cause lodging, delay in maturity, and late tillers. Late tillers may be produced on plants growing in thin stands, resulting in uneven ripening of the grain and consequent greater difficulty in drying. When fields are heavily infested with weeds, the grain coming from the combine will contain a high percentage of weed seeds, leaves, and stems which are usually much higher in moisture content than the rice. Unless the grain is cleaned prior to drying, the conditioning process becomes more complicated and more costly. Fields which are not properly leveled, levees which are poorly located or constructed, and water application which is mishandled give rise to uneven stands of rices and promote excessive weed growth; the result is a reduction in yield and lowering of crop quality. An improper seeding time also may cause a loss in quality and an increase in drying cost, and complicate storage problems (1). The use of desiccating chemicals for the preharvest drying of rice may be feasible when fields are weedy or lodged, when the rice is to be used for seed, when further drying will be by aeration, or in cases where late-sown rice is physiologically

[1] Numbers in parentheses refer to Literature Cited, p. 51.

[2] Kramer, H. A. Unpublished data on rough rice equilibrium moisture.

mature but is not drying down because of low temperature (21). For satisfactory results, however, desiccants should be applied only after the moisture content of the grain has dropped to 28 percent and the crop harvested before the content drops to 17 percent (20).

Field Handling and Harvesting

Rice quality may be materially affected by the handling practices during harvesting. The adjustment of the combine and the speed of operation were found to be of more significance than the make or type of equipment used (46). Tests in 38 fields of the Nira variety in Arkansas showed combine losses ranging from 1.04 to 14.86 percent. Hulling and breaking are the major mechanical damages which occur to combined rice and in most instances these may be substantially reduced by proper combine adjustment and operation. Rice harvested at moisture contents of 20 percent and over tends to deteriorate rapidly, so the interval between combining and conditioning is important to maintain quality. If drying facilities are not readily available, undried rice with 18 to 24 percent moisture may be kept satisfactorily for periods of a week or 10 days by use of aeration. Time of harvest also is an important consideration in determining yield and milling quality (47, 59).

STRUCTURE OF THE RICE KERNEL

Microscopic and radiographic studies of the kernel structure of rice provide information which is basic to the interpretation and evaluation of the results obtained from application of the various methods and practices for conditioning and storing of rice. These studies also may be useful by indicating new approaches which may lead to the solution of problems encountered in conditioning and storage.

Microscopic Studies

The microscopic structure of the rice kernel has been studied at the Northern Utilization Research and Development Division, Agricultural Research Service, USDA, Peoria, Illinois. Modifications of methods developed there for preparing corn and wheat kernels for detailed studies were employed for preparing sections of rice kernels (23).[3]

A longitudinal section through the center of a kernel of Zenith variety (Figure 1) shows the relationship of parts within the rice kernel. The major parts, which appear clearly at low magnification, are the pericarp, endosperm, and germ. The percarp consists of several layers of cells, which form a protective covering around the true seed. A seed coat, invisible at low magnification, surrounds the germ and endosperm and forms a further protection to them. The pericarp, which constitutes a portion of rice bran, is fibrous and of little or no value as human food. Fortunately for the rice miller, it is structurally a separate entity. Its removal from the seed does not require the breakage of other parts.

At the top of the mature kernel, one or both styles are often visible (Figures 1, 2, and 3). In some cases, microscopic examination of the top of the style shows the stigma, often with some pollen grains still attached to it (Figure 3). Together, stigma and style form a pathway for the entrance of the pollen content at the time of pollination. Mold spores may enter cereal grains with the pollen. This may explain why molds are often found inside cereal grain kernels at maturity. Molds in cereal grains occur especially in the inner layers of the pericarp and around the germ.

The kernel attachment regions, where the kernel is broken away from the plant, has tissues through which molds can enter more readily than through the pericarp. Moisture can also enter at the attachment region, where there are capillary spaces between the cells. While moisture entering the kernel chiefly takes this route, the moisture expelled from the kernel during drying passes out largely through the pericarp.

[3] Also MacMasters, M. M. Private communication, 1958.

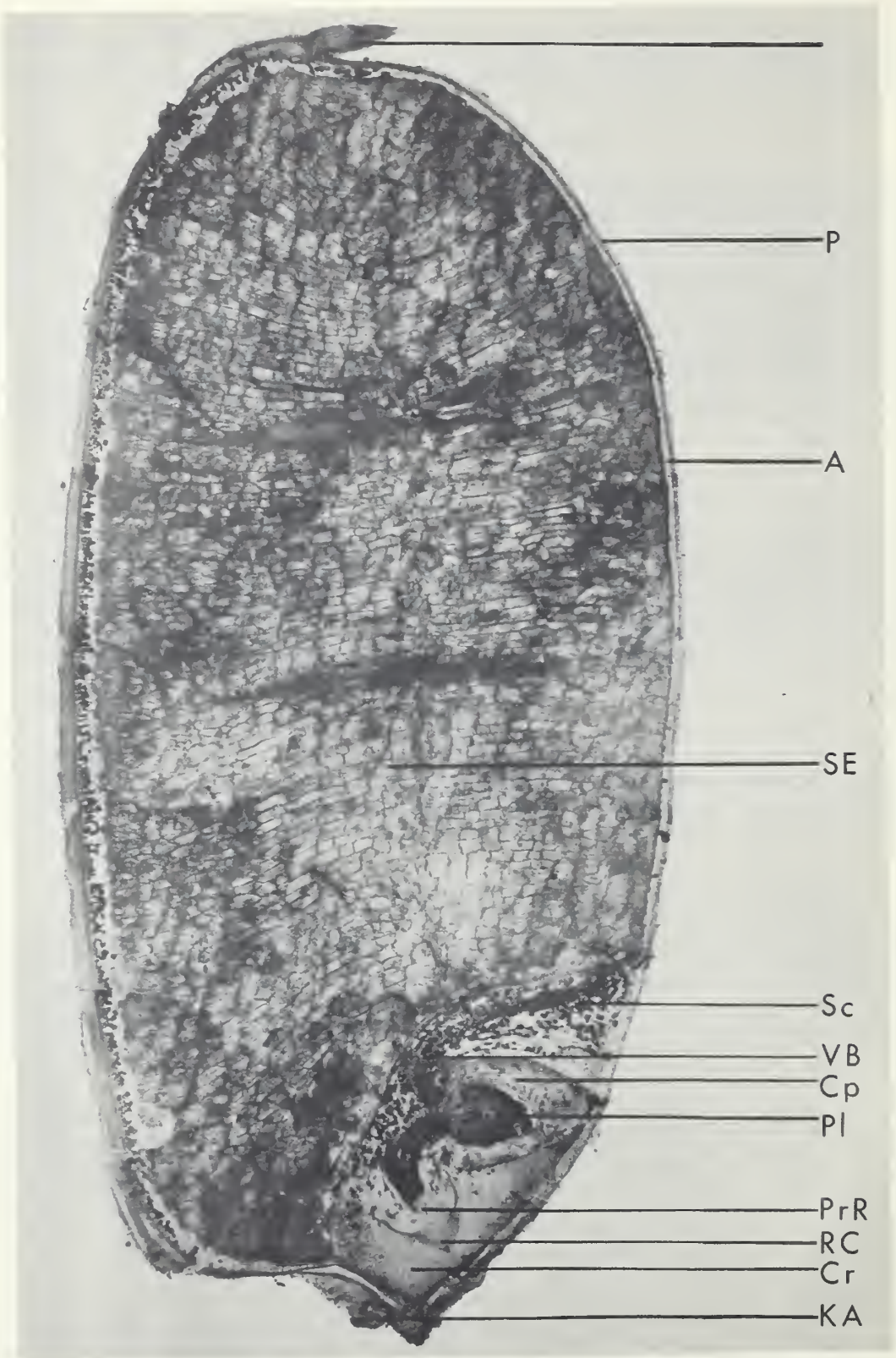

Figure 1.--Longisection through the middle of a kernel of Zenith variety rice. Shown are the style (S), pericarp (P), endosperm (E) composed of starchy endosperm (SE) and aleurone layer (A), germ (G) composed of scutellum (Sc) and embryonic axis (EA), and the kernel attachment region (KA).

Figure 2.--Style at upper tip of a kernel of Zenith variety rice.

Figure 3.--Stigma and style removed from a mature kernel of Zenith variety rice. Pollen grains are evident, still on the stigma.

The endosperm and the germ are the major parts of the seed. The endosperm comprises two parts. The major portion is composed of cells filled chiefly with starch and is therefore known as the starchy endosperm. The outermost, thin layer of endosperm cell is quite different, since it contains oil and protein but no starch. It is known as the aleurone layer. The starchy endosperm cells are mostly bricklike in shape (Figures 1 and 4), except in the center of the kernel where they are polyhedral (Figures 1 and 5). The bricklike shape and the arrangement of these cells, radially from near the center to the sides of the kernels, appear to favor checking and breaking across the kernel during drying and milling. The aleurone layer is usually removed as part of the bran. If this oily layer is left in milled products, they tend to develop rancidity.

The germ is a complicated structure which, through germination, develops into the young plant. The embryonic foliage leaves (Figure 6) or plumule, and the embryonic primary root (Figure 7) of the young plant are already present in the germ. They form the embryonic axis. The plumule is ensheathed by the coleoptile; the primary root, with its tip protected by the root cap, is ensheathed by the coleorhiza. Partially surrounding all of these parts, and comprising the remainder of the germ, is the scutellum. The scutellum not only contains food, such as oil and protein, for the germinating embryo but also acts as an absorbing organ to transfer nutrients from the endosperm to the young plant during germination. The epithelial layer of the scutellum (Figure 8), which lies adjacent to the starchy endosperm, is active in this function. Provascular bundles in the scutellum and embryonic axis are pathways for movement of dissolved nutrients. Both the bran and germ of rice contain unsaturated glyceride oil, and their inclusion in rice products favors development of rancidity. Therefore the germ is usually removed during milling. The separation is facilitated by the germ and endosperm being separate structures, with no continuity of tissues between them.

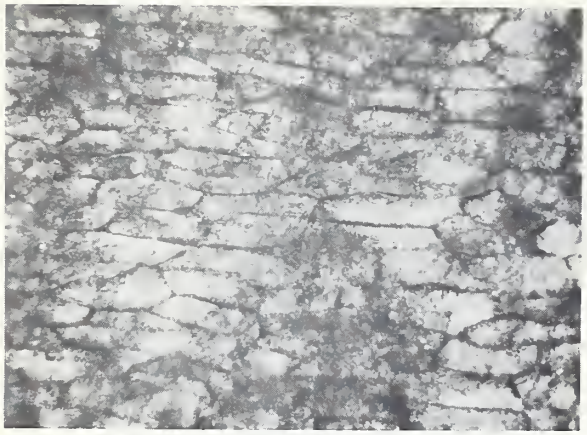

Figure 4.--Section through starchy endosperm cells near the pericarp in a kernel of Zenith variety rice.

Figure 5.--Section through starchy endosperm cells in the center of a kernel of Zenith variety rice.

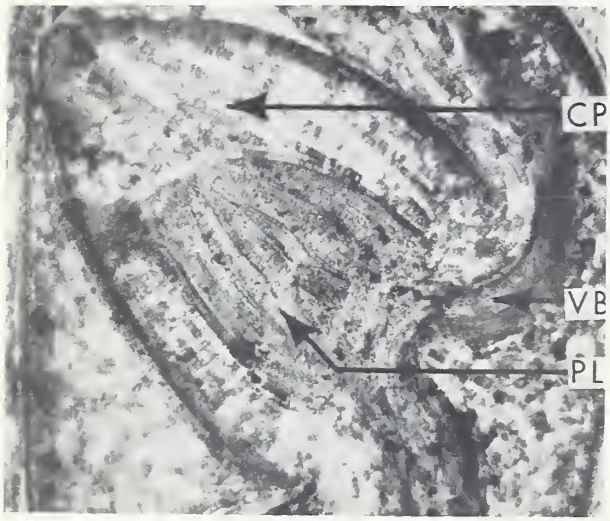

Figure 6.--Longisection through the upper part of embryonic axis in germ of a Zenith variety rice kernel. Shown are the plumule (PL) ensheathed by the coleoptile (Cp), and the provascular bundle (VB).

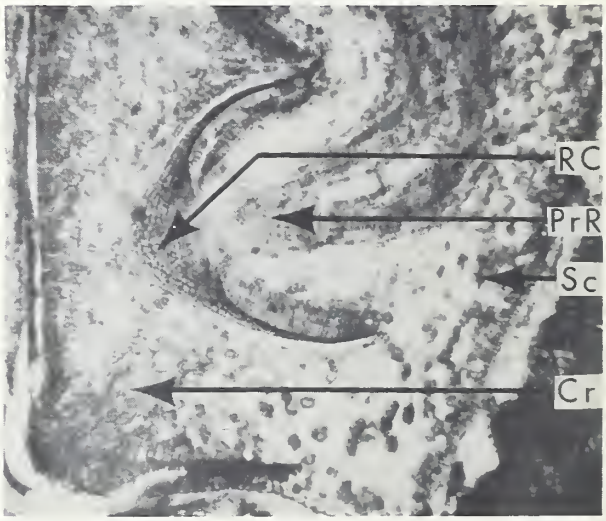

Figure 7.--Longisection through the lower part of embryonic axis in germ of a Zenith variety rice kernel. Shown is the primary root (PrR) with its tip protected by the root cap (RC), both ensheathed by the coleorhiza (Cr). The lower part of the scutellum (Sc) is also visible.

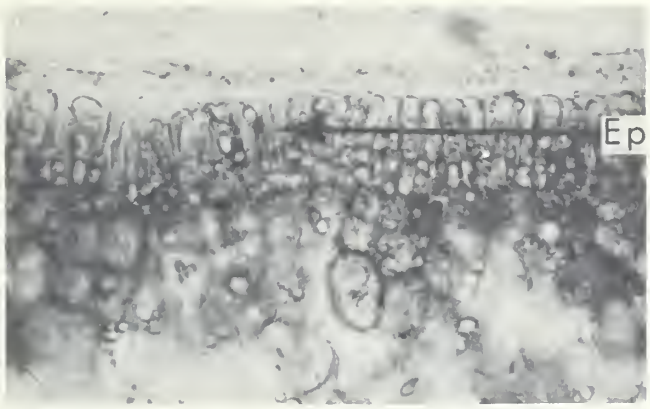

Figure 8.--Section through a Zenith variety rice kernel where germ and endosperm meet. The scutellar epithelium (Ep) is clearly visible.

Radiographic Studies

Recent work has indicated the possible adaptation for other uses of the radiographic method of detecting internal infestation (13). The use of soft, long wavelength X-rays may prove helpful in determining the degree of checking in rice kernels, in determining the efficiency of fumigation and in the selection of rice for processing (54). X-ray techniques have been successfully applied by Milner and associates to the determination of the internal infestation of rice by the rice weevil as well as to the detection of checking of the kernel (36, 48-52).

Henderson (15) in an investigation of the causes and characteristics of rice checking employed the radiographic technique for studying the number and type of checks arising from differences in conditions of handling prior to and during drying of the grain. Results of the study showed that checking began at the center of the kernel during drying and progressed toward the minor circumference of the kernel. There may be single or multiple checks and fractures in many directions as checking progresses. Dew also produced checking in the grain. In addition, it was found that an increase in temperature produced checking. Although not conclusive, data indicate that checking results from a moisture and/or temperature increase. When the outer portions of the kernel take on moisture or increase in temperature, they expand. Since the central portions are inelastic, internal pulling apart results and checks or fissures result.

A high percentage of grains which appear to be sound externally contain internal checks or faults. Since these faults weaken the kernel structurally, failure often results during the milling process. A fast moisture removal rate would be expected to cause failure from the outer surface toward the center. But since X-ray examination showed this phenomenon to be nonexistent, checking during fast drying must be due to an increase in temperature gradient of the rice surface layers, a condition producing fast drying, rather than to an excessive decrease of moisture in the surface. Multiple stage drying would reduce the maximum temperature gradient through the kernels and thereby reduce internal checking.

Hogan, Larkin, and MacMasters (23) in a study of cereal quality measurement demonstrated the utilization of the X-ray technique for the rapid examination of rough rice for cracks, checks, insect damage, and immature seed. Radiographic evidence of checking in grains of rough rice was confirmed by photomicrographs of sections of the same kernels. The study indicated a poor correlation between breakage counts as revealed by radiographic examination and commercial mill yields for selected lots of rice. This lack of correlation may have been due either to uncontrolled factors which affected the commercial milling yield or to invisible checks in the sample of rough rice tested which were not detected by the radiographic technique.

Results of the investigation suggest that X-ray examination of the rice grain before and after harvesting may prove to be useful in research on harvesting procedures and harvesting equipment. Similarly, serious breakage of rice during various stages in the drying process can be revealed quickly by X-ray examination. If desired, a quick X-ray test can provide a permanent record of breakage and insect infestation of a rice sample.

COMPOSITIONAL CHANGES IN RICE DURING DRYING AND STORAGE

Experiments at the Southern Regional Research and Development Division during the rice harvesting seasons of 1950, 1951, and 1952 demonstrated the effects of time and temperature on the viability of rough rice of different moisture contents (44). Both medium-grain and long-grain varieties were used. It was found that for rough rice of each moisture content there is a temperature of heat treatment below which there is no decrease in viability. The "zone of heat damage," i.e. the range between the temperature at which heat damage to viability just starts and the temperature at which it is just complete, is a narrow one. The extent of this range for a heat treatment period of 30 minutes appears to be between 8° and 12° F. The range is about the same for rice of different moisture contents but is higher on the temperature scale the lower the moisture content of the rice. Within the zone of heat damage for rice of a given moisture content the degree of destruction increases as the temperature increases; also, the longer the rice is heat treated, the greater are its losses in germination capacity and germination vigor.

The resistance of rough rice to the impairment of its viability by heat varies inversely as its moisture content. When the approximated temperatures defining the range of heat damage to viability were plotted for several samples of rice of different moisture contents, a scatter type diagram was obtained in which the zone of heat damage is clearly indicated. Such information should prove of practical value in research and in commercial operations involving the heat treatment of rice and should serve as a heat damage prediction chart for viability.

Studies on compositional changes during drying made by the Western Regional Research and Development Division relate to the effect on brown rice stability of steaming the paddy before drying and milling (26). Results showed that rate of formation of free fatty acids was reduced by this procedure, but that the tendency to rancidify was accelerated as though some natural inhibitors had been destroyed. The effects of moisture and temperature on the course of free fatty acid development in brown rice are illustrated by Figures 9 and 10 for rates at 77° F. and for initial rates at several moistures and temperatures (33).

Solubility in dilute alkali of nitrogen-containing compounds (chiefly proteins) of rough rice of 4 moisture contents (12 to 16 percent) stored at 60°, 77°, 90°, and 100° F. for 18 months decreased appreciably at the 2 higher temperatures, and for the highest moisture rice (15.7 percent moisture) at 77°. Solubility decreases became marked at 100°, amounting to about 45 percent loss in 18 months at 13.3 percent moisture and over 50 percent in 9 months at 16 percent moisture.[4] This decrease in protein solubility is generally assumed to be an indication of loss of nutritive values.

The free amino acids of parboiled rice were found to be reduced in individual amounts after an accelerated storage test (128 days at 180° F.). Greatest losses occurred in asparagine, methionine, and cystine. Marked reduction of glutamic acid and alanine was also found (32). Information on changes in plant acids of rices and their relation to other compositional changes during storage is now being collected.

Fat acidity surveys of several hundred samples of sound and damaged rough rice samples have led to the establishment of a maximal fat acidity value for rice showing little or no deterioration (4). The tentative fat acidity limit for rough rice is 25 meq. per

[4] Houston, D. F., and coworkers. Unpublished reports.

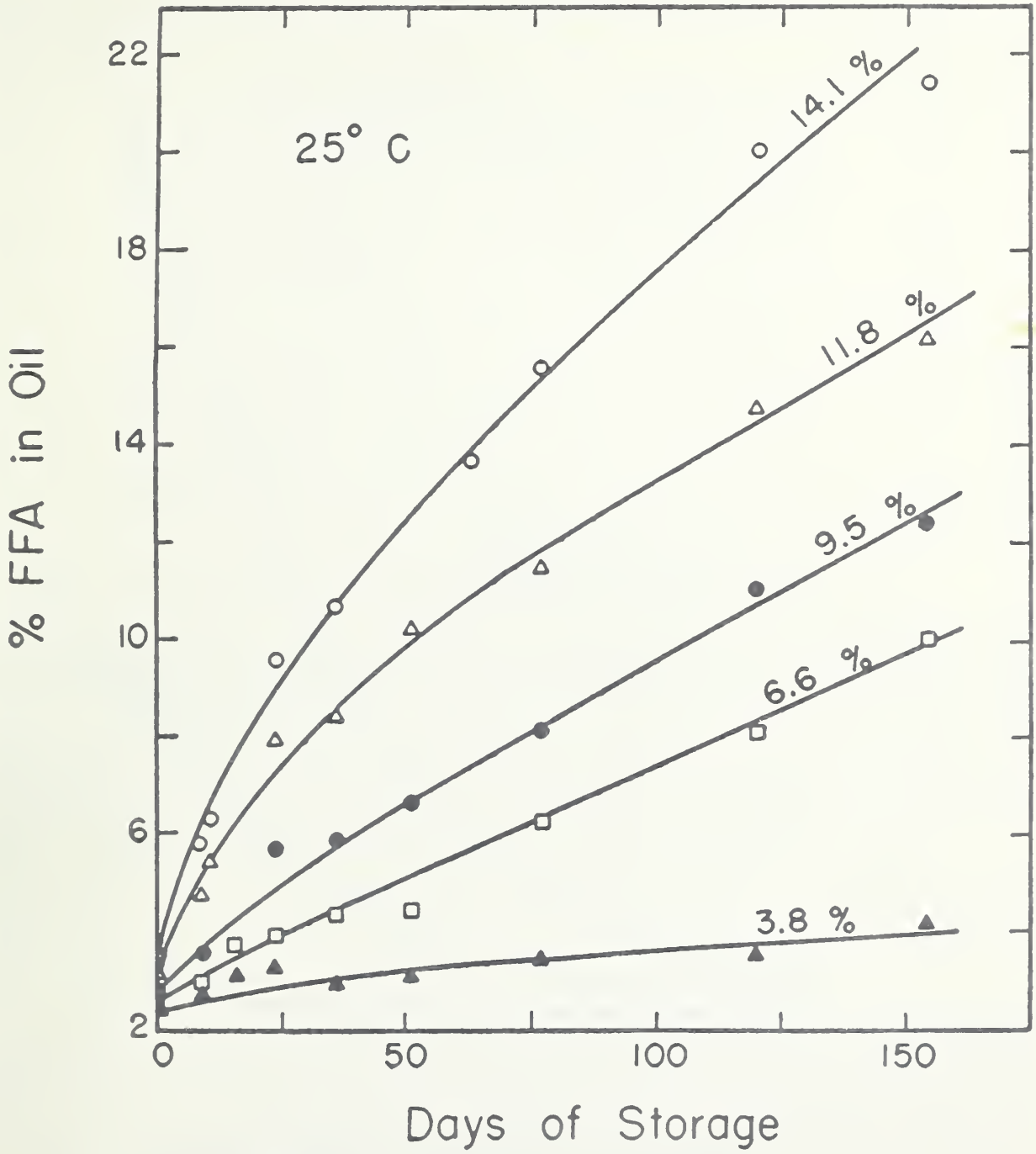

Figure 9.--Development of free fatty acids in commercial brown rice of different moisture contents stored at 77° F.

100 g. of rice. Damaged rice showed higher values depending upon the degree and type of damage. A curvilinear relationship was found to exist between fat acidity and the moisture content of the grain at the time of extraction.

That active plant lipases (fat-splitting enzymes) are present in the bran fraction obtained during rice milling is shown by measurements reported in Table 1. The destruction of hydrolytic activity through steaming the rough rice and the decrease during storage are also illustrated by these data (30).

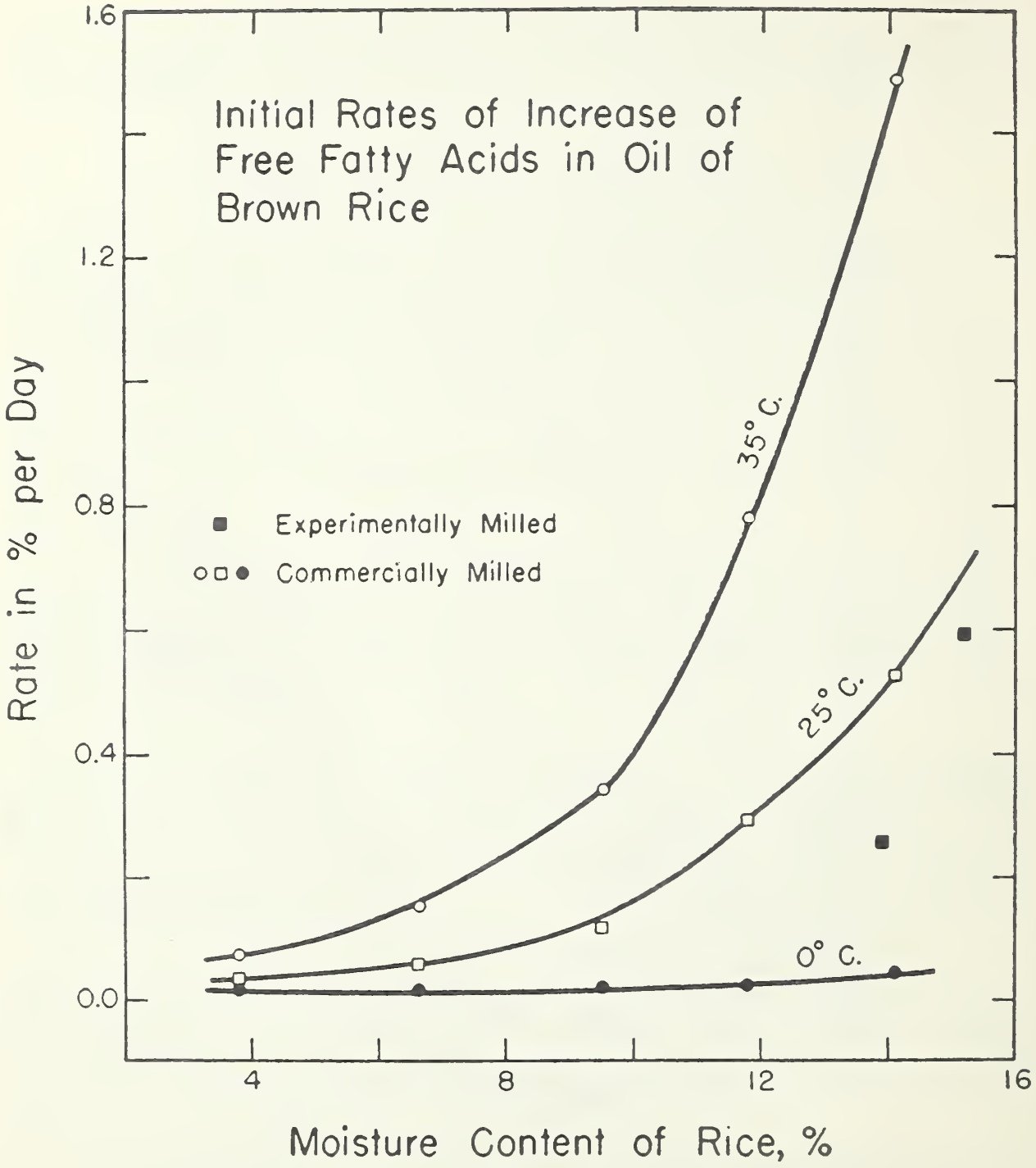

Figure 10.--Variation of initial rates of free fatty acid formation with moisture content of brown rice at three temperatures.

Palatability tests and measurements of some physical and chemical characteristics of rice were made on samples of Century Patna 231 and Rexoro rices that had been dried at room temperature, 120°, 140°, and 160° F. (6). Color, cohesiveness, and flavor were rated by a sensory testing panel. Measurements of volume, water absorption of rice, and amylose starch and total solids of the residual cooking liquids, and reaction to dilute alkali solution were made. Although significant variations in some of the palatability characteristics and physical, chemical, and alkali tests were observed for samples dried

TABLE 1.--Lipase activity of rice bran fractions

Sample	Description of bran	Activity[1]
		Units
1	Defatted Western bran No. 1; portion passing a 24-mesh sieve	0.33
2	Same, ground to pass 60-mesh sieve	.34
3	Same as 1, but steamed 4 min. at 212° F	.01
4	Defatted Western bran No. 2; screened to pass a 24-mesh sieve and ground to pass a 60-mesh sieve	.28
5	Defatted Western bran No. 3; portion passing a 24-mesh sieve	[2] 0.23-0.25
6	Defatted Western bran No. 4; screened to pass a 24-mesh sieve and stored 2 years at room temperatures before extraction of oil (70% free fatty acids as oleic)	0.07
7	Defatted Southwestern bran No. 1, as received	.19
8	Same; portion passing 24-mesh sieve	.29
9	Same as 7, but ground to pass 60-mesh sieve	.28
10	Same as 8, but stored 39 days before extraction of oil (oil contained 70% free fatty acids as oleic)	.18
11	Defatted Southwestern bran No. 2; portion passing 24-mesh sieve	.21

[1] Activity is in arbitrary bran lipase units per kilogram.
[2] Range of values obtained by 2 operators in a series of tests.

at different temperatures, the variations were not linearly related to successive increases in temperature, nor were they similar for the varieties. For Rexoro rice, drying at 120° appeared to result in better color, less off-flavor, and less cohesiveness in cooked rice than the other drying temperatures employed. For Century Patna rice, a better color resulted when room temperature or 140° was used as the drying temperature. The varying temperatures used in drying within the limits studied did not affect other palatability characteristics. The temperature used for drying rough rice did not appear to influence the behavior of the milled samples of Century Patna 231 and Rexoro rice when immersed in dilute alkali. Forced-air drying of rice at elevated temperatures apparently did not cause marked improvement or deterioration in the cooking quality of rice (6).

Much remains to be learned about the composition of and changes in the major components of rice starch and proteins during drying and storage. This is especially true with the starch fraction and in particular with the nonamylose, "amylopectin," fraction. It has become increasingly apparent that the nonamylose fraction of rice starch may be more influential in cooking behavior than previously thought.

Knowledge of the minor components of rice is more fragmentary. These compounds, present only in relatively small amounts, are usually readily soluble, easily transported, and sensitive to reaction. They form a pool of reactive material whose overall composition shifts in response to imposed stresses. Changes in the component ingredients of this mixture may well serve as keys to the differing behavior of rice resulting from conditioning, storage, or processing. More basic information is needed about the minor constituents of rice--their changes resulting from outside influences and their interrelationships in rices of prime and deteriorated qualities.

PHYSICAL PROPERTIES OF RICE RELATED TO DRYING AND STORAGE

Hygroscopic Equilibria

As the moisture contents of hygroscopic materials seriously affect the storage and keeping qualities of such materials, equilibrium moisture data are directly applicable to the solution of storage, processing, and drying problems. Rice, like other grains, is hygroscopic in nature--that is, it gains or loses moisture when the vapor pressure of

water in the space surrounding the grain is greater or less than the vapor pressure exerted by the moisture within the grain. The moisture content of various fractions from artificially dried and naturally dried rough rice in equilibrium with atmospheres of different relative humidities are shown in Table 2 (35). Moisture equilibrium data for a number of edible forms of rice are given in Table 3.

TABLE 2.--Percentage of moisture (wet basis) of various fractions from artificially dried and naturally dried rough rice in equilibrium with atmospheres of different relative humidities

Description of sample	Moisture in rice at indicated relative humidity (%) of atmosphere								
	10	20	30	40	50	60	70	80	90
	%	%	%	%	%	%	%	%	%
Rough rice[1].....	4.4	6.5	7.9	9.1	10.4	11.8	13.2	14.8	17.6
Rough rice[2].....	4.6	6.6	8.0	9.3	10.6	11.6	12.6	13.8	17.0
Polished rice[1].....	5.2	7.6	9.2	10.5	12.0	13.4	14.8	16.4	18.8
Undermilled[2].....	4.6	7.0	8.6	10.0	11.4	12.8	14.2	15.4	18.4
Bran[1].....	5.0	6.4	8.0	9.0	10.0	11.0	12.4	14.8	18.0
Bran[2].....	4.6	5.8	6.6	7.4	8.3	9.2	10.6	(Moldy)	---
Hulls[1].....	3.7	5.4	6.8	8.1	9.5	10.8	11.8	12.9	15.3
Hulls[2].....	3.7	5.4	6.8	7.9	9.1	10.1	10.8	11.6	14.0
Polish[1].....	5.3	7.0	8.2	9.2	10.1	11.0	12.4	14.5	18.0

[1] Field-dried rough rice; initial moisture 16.8%.
[2] Rice which had been artificially dried prior to receipt at mill; initial moisture 12.8%.

Source: Karon, M. L., and Adams, M. E. (35).

TABLE 3.--Comparison of equilibrium moisture contents of edible whole-grain rices at various relative humidities

Type of rice	Temperature	Original H_2O	Equilibrium moisture of rice at indicated relative humidity (%) of atmosphere								
			10	20	30	40	50	60	70	80	90
	^{o} F.	%	%	%	%	%	%	%	%	%	%
Parboiled.....	100	12.7	4.9	7.0	8.4	9.8	11.1	12.3	13.3	14.8	19.1
Parboiled.....	77	13.1	5.9	8.0	9.5	10.9	12.2	13.3	14.1	15.2	19.1
Brown (24).....	77	14.8	6.2	8.0	9.5	10.9	12.3	13.5	14.8	16.2	19.1
White (35).....	77	15.8	5.2	7.6	9.2	10.5	12.0	13.4	14.8	16.4	18.8
Quick-cooking.....	77	9.5	5.5	7.4	8.9	9.7	10.5	11.5	13.1	15.4	20.1
Quick-cooking (11)[1]	100	---	3.7	5.5	7.0	8.2	9.2	10.3	11.7	13.6	---

[1] Also Elder, L. W., private communication.

Rice approaching moisture equilibrium from a dry condition will reach a lower moisture content than when approaching the same equilibrium from a moist condition, at least within the range 25 to 75 percent relative humidity. This difference may be as much as 1 percent for raw rices, or up to 2 percent for processed rices in which the starch has been gelatinized (29). It has been shown that rough rice at moisture contents between 12.6 and 14.1 percent may be in equilibrium with a relative humidity of 75 percent (7).

Reaching equilibrium moisture conditions may require several weeks, but the major portion of the moisture change occurs in a few days. Hence, relatively short periods of adverse storage conditions as influenced by weather can produce marked changes in the

moisture content of rice exposed to the air. The maximum moisture contents at which rough rice will store satisfactorily under the normal conditions in humid regions lie between close limits. For safe storage in ordinary bins of wood or steel, Coonrod (8) has advocated a maximum moisture content of 13.5 percent for periods less than 6 months and 12.0 percent for over a 6-month period. The maximal length of storage has not been determined. Increased susceptibility to deterioration of high moisture rice can be compensated for by use of aeration. When rice was stored in 1,000-bushel bins, 1 lot of 16.1 percent moisture content, when not aerated, went to sample grade in 9 months, but similar lots when periodically turned or aerated with a fan did not fall below No. 2 in 22 months (37).

It is interesting to note the effect which can occur when rice packed in relatively moisture proof containers is moved from a cool to a hot storage. A temperature increase of this packed rice from 77° to 100° F. with a 12 to 14 percent moisture content will result in an increase of 8 to 10 percent in the relative humidity of the package atmosphere. This may bring the relative humidity to above 75 percent and change the storage condition from a relatively safe one to a condition in which mold growth could occur rather rapidly (29).

Curves of relative humidity versus moisture content for most rices show a more rapid increase in moisture content when relative humidity is above 70 to 75 percent (7, 22, 35). For safe storage, humidity should remain below this range. At temperatures between 63° and 75° F. mold growth increases with increasing moisture content above 15 percent and the viability of the seed decreases (9).

The role of fungi in causing heating and spoilage in grain with moisture contents in equilibrium with relative humidities of 75 percent and above has been demonstrated by several workers (9, 48). The explanation is probably that surface of the individual grains will remain dry below 75 percent. Molds and bacteria, which cause damage, are present in a latent form in this type of dry surface and thus remain inactive under these conditions.

When the equilibrium moisture content of rice is plotted against relative humidity, the characteristic S-curve (sigmoid), which is typical for most cereal grains, is obtained. This form, however, is inadequate to permit accurate extrapolation of experimental data beyond the measured range of variables of the experiment. Several investigators have derived equations based on theoretical considerations and applied graphical methods for a clearer description and presentation of the hygroscopic equilibrium phenomena and have tested the equations against observed data (14, 22, 55).

The moisture content-relative humidity relationship of rice is an important factor to be considered in the drying process. Humidification of the drying air remarkably improves the quality of the rice so dried. For example, at 110° F. 1-pass drying of the Caloro variety of 24-percent moisture content and about 33 percent relative humidity produced the same head rice yield as 3-pass drying with unhumidified air (17). Higher humidities produced even higher head rice yields. A longer drying time is needed with humidification. The 3-pass drying required 2.2 hours; 1-pass humidified drying required 4.5 hours to yield the same quality product. Checking of rice increases at a faster rate as drying progresses at any given humidity, as shown by the fact that during the removal of the first 4 percent of moisture at 130° the checking amounted to 12 percent, but 45 percent checked during the removal of the last 4 percent of moisture. These results indicate the possibility of increasing both yield and quality of column-dried rice by using elevated humidity drying air. However, because this process extends the drying time considerably, a different procedure, one which would yield satisfactory capacity, is required--such as using stage single-pass drying (starting with high temperature-low relative humidity air to remove the first few percent of moisture, finishing with lower temperature-higher relative humidity air), reducing the number of passes by humidifying during one or more passes, or using additional drying capacity to accomplish complete drying with low temperature and high relative humidity.

Rough rice samples of 20 different varieties, taken from the 1949 and 1950 field plot variety tests grown at the Texas Rice Pasture Experiment Station and stored under uniform conditions of atmospheric temperature and humidity were investigated for comparative equilibrium moisture contents.[5] A relatively constant temperature was maintained. The varieties consisted of early, midseason, and late maturing types of short, medium, long, long slender, and medium long slender grain types as well as pubescent (rough) and nonpubescent (smooth) hull types. The average final moisture content of the 20 varieties was found to be 9.73 percent for 1949 samples tested in 1950, 9.89 percent for 1949 samples tested in 1951, and, for the same varieties harvested in 1950, 10.11 percent when tested in 1951. The difference between the 1949 and the 1950 samples tested in 1951 was significant. The average moisture contents of the 20 varieties were found to be significantly different among the samples tested in both 1950 and in 1951. Table 4 presents the average final moisture content (wet basis) for the 20 varieties for the 2 replications of the samples tested in 1950 and for the 4 replications of the samples tested in 1951. These data show that the moisture content of certain varieties was consistently low; in other varieties this factor was consistently high; but the majority of the varieties showed considerable variation from year to year and from test to test. Improved Bluebonnet, LaCross, and Rexark can be considered as consistently high varieties. Zenith, Fortuna, Prelude, and Early Prolific can be considered consistently low varieties. All other varieties were too inconsistent to be classified as either high or low. Within a single year there are significant differences between varieties; however, these differences are not consistent for crops grown in different years. It was concluded that the environmental conditions under which a crop is grown influence the final equilibrium moisture for a single variety.

TABLE 4.--Average final moisture contents (wet basis) for 20 rice varieties grown in 1949 and tested in 1950 and for the same varieties grown in 1949 and 1950 and tested in 1951

Variety	1949 Crop, 1950 test	1949 Crop, 1951 test	1950 Crop, 1951 test
	Percent[1]	*Percent*[1]	*Percent*[1]
Zenith	9.35 a	9.65 ab	9.85 ab
Fortuna	9.45 ab	9.65 ab	9.70 a
Century 52	9.57 bc	9.85 bcde	9.90 bc
Bluebonnet	9.62 bc	9.55 a	10.15 def
Prelude	9.62 bc	9.75 bc	9.95 bcd
Blue Rose	9.63 bc	10.20 h	9.85 ab
Early Prolific	9.65 bcd	9.80 bcd	9.95 bcd
Mira	9.70 cde	10.15 gh	10.10 cdef
RU	9.77 cde	10.00 defgh	10.10 cdef
TP	9.78 cde	9.80 bcd	10.00 bcde
B438A1	9.78 cde	9.80 bcd	10.10 cdef
Bluebonnet 50	9.78 cde	9.75 bc	10.10 cdef
Magnolia	9.78 cde	10.05 efgh	10.00 bcde
TP 49	9.80 cde	9.95 cdefg	10.20 ef
Caloro	9.80 cde	10.10 fgh	9.90 bc
Improved Bluebonnet	9.87 de	9.95 cdefg	10.65 g
LaCross	9.88 de	10.00 defgh	10.30 f
Century 231	9.92 e	9.75 bc	10.60 g
Rexark	9.92 e	10.10 fgh	10.25 f
Rexoro	9.93 e	9.90 cdef	10.55 g

[1] Means with the same letters following are not significantly different at the 5-percent level. Means with different letters following are significantly different at the 5-percent level.

[5] See footnote 2.

Diffusion of Moisture

It has been possible to evolve a generally applicable law of drying through research investigation. An analysis by Schmidt and Hukill (57)[6] of data obtained by Aldred and Kramer shows a general drying pattern. A small laboratory drier with temperature, humidity, and air velocity controls was used to test four rice varieties (Caloro, Zenith, Bluebonnet, and Rexoro). Eighteen drying tests were performed on each variety and each test used a different drying air condition. Temperatures of the drying air ranged from 90° to 142° F. and the relative humidities ranged from 9 to 84 percent. Saturation deficits of the drying air ranged from 0.3 to 5.6 inches of mercury. Saturation deficit is the difference between the saturated aqueous vapor pressure at the dew point and at the dry bulb temperature. Its value is dependent on both temperature and humidity of the drying air. It has been considered by many researchers as being a measure of drying rate.

Samples of rice were dried in one continuous operation to approximately 13 percent moisture content. Drying differed from the conventional drying methods in that the rice was dried in shallow layers, thus exposing every kernel to the given temperature and humidity of the drying air. Head rice yields and germination determination were made on all rice samples before and after drying. Table 5 shows the average losses in head

TABLE 5.--Average losses[1] in head rice yield and in germination in drying 4 varieties of rice at 18 different drying air conditions, Beaumont, Tex., 1949

Test No.	Drying air condition			Av. moisture content of rice before drying (W. B.)	Av. loss in head rice yield	Av. loss in germination
	Saturation deficit	Temperature	Relative humidity			
	In. Hg	*°F.*	*Percent*	*Percent*	*Percent*	*Percent*
1.....	0.3	90	80	22.6	18.0	0.4
2.....	.4	110	84	24.3	9.2	10.0
3.....	.6	100	69	24.0	9.6	2.5
4.....	.7	90	51	23.4	3.5	5.6
5.....	1.2	100	32	20.8	-2.5	-5.0
6.....	1.3	130	71	25.0	-2.4	17.9
7.....	1.4	110	49	24.8	-7.8	-1.1
8.....	1.8	130	61	25.0	-0.6	19.4
9.....	2.0	110	26	23.1	-0.2	-0.9
10.....	2.6	130	43	26.1	-8.8	24.2
11.....	3.2	130	28	22.3	11.5	10.5
12.....	3.3	142	47	25.3	14.8	52.2
13.....	3.6	130	20	20.6	12.6	5.5
14.....	4.0	130	12	20.3	16.5	-1.9
15.....	4.0	142	36	22.8	24.2	34.0
16.....	4.8	142	24	22.5	31.6	29.9
17.....	5.2	142	17	23.5	41.6	31.8
18.....	5.6	142	9	19.7	30.1	6.0

[1] These losses are the differences between yield and germination percentages of the room air dried and heated air dried rice. A minus value indicates that the yield of head rice or germination was higher in the heated air dried rice.

Source: Schmidt, J. L., and Hukill, W. V. (57).

[6] Also Hukill, W. V. Unpublished reports.

rice yield and in germination in drying 4 varieties of rice at 18 different drying conditions. The effects of drying with heated air on the yield of head rice and on the germination of rice are shown by differences between the yield and germination of the rice dried under the conditions of the test and the rice dried with room air. Lower yields were obtained when rice was dried with saturation deficits greater than 2.0 inches of mercury than when dried at room temperature. Losses in germination were found when drying with air temperatures greater than 110° F. However, the losses (reduction in yields as compared to room dried rice) obtained in head rice yields in drying depended somewhat on the variety of the rice, and the losses in germination depended on the initial moisture content of the rice. In general, as the saturation deficit and temperature of the drying air increased, the loss in yield and germination also increased. Statistical analysis revealed that losses in head rice yield were related more closely to saturation deficit than to temperature of the drying air. Germination losses on the other hand were closely related to the temperature of the drying air. In addition, germination losses were also related to the initial moisture content of the rice.

Although the initial moisture content of the rice was not a factor affecting the yield of head rice in drying, the variety of the rice was. The yield of the short- and medium-grain varieties, Caloro and Zenith, were lowered more in drying than the yield of the long-grain varieties, Bluebonnet and Rexoro. Loss in yield by the shorter grain varieties when drying with a saturation deficit of 1.0 to 2.0 inches of mercury was about the same as the loss in yield by the long-grain varieties when drying with a saturation deficit of 3.0 to 4.0 inches of mercury. This indicates that the long-grain varieties tested could be dried at a faster rate. Air velocity in drying had very little effect on the head rice yield and the germination of the rice.

In a series of tests with grain sorghum the pattern of moisture loss appeared to be consistent throughout the range of initial moisture, air velocities, air temperatures, and humidities used in the tests. Tests with oats and soybeans partly confirmed the validity of the pattern of moisture loss, and it may be expected to apply to rice as well. Briefly it can be described as follows: The resistance to moisture flow can be divided into two parts, that due to the air film and that due to the necessity of the moisture to travel from the interior of the kernel to the surface. The former resistance is inversely proportional to about the one-third power of the air velocity. The flow through both the air film and the kernel appears to be proportional to the square of the vapor pressure difference at a given temperature. But the air temperature varies from test to test; consequently it appears that moisture flow is proportional to the saturation vapor pressure for the temperature. With respect to the kernel alone this results in two phases of flow. The first phase, during which about one-third of the moisture is lost, is assumed to be the period before the moisture content at the center of the kernel begins to change; the second phase is assumed to be the remainder of the drying period, when the moisture drops throughout the kernel.

MICROFLORA OF STORED RICE

Populations of molds, yeasts, aerobic and anaerobic bacteria, and actinomycetes determined on storage samples of California 1953-harvest Caloro rough rice (31), together with mold and yeast populations determined on similar rice from the 1954 and 1955 harvests,[7] are shown in Table 6. Subsequent laboratory and field storage tests on rough rice with these microbial populations showed that only the molds increased in relation to increased deteriorative changes in the rice.

Environment had a major role in governing the changes of molds; other microflora decreased during controlled laboratory storage when moisture content ranged from 11.2 to 16.8 percent at 70° and at 90° F. At 60° yeast populations decreased slowly. They showed considerable fluctuations in rough rice of 12 to 15 percent moisture content during storage for 3 years at 34°, 20°, and even at -20°, while mold counts remained largely unchanged (40).[8]

[7] Houston, D. F., and coworkers. Unpublished reports.

[8] Also Houston, D. F., and coworkers. Unpublished reports.

TABLE 6.--Types of microflora of stored rice

Harvest year	Populations of microflora, by type				
	Molds	Yeasts	Actinomycetes	Aerobic bacteria	Anaerobic bacteria
	Thousands per gram	*Millions per gram*	*Millions per gram*	*Millions per gram*	*Millions per gram*
1953.....	2.5-50	0.5-5	21-88	30-124	12-68
1954.....	<.1-6	1.1-24.6	---	---	---
1955.....	<.1-6.1	.5-9.8	---	---	---

Increases in mold populations occurred during storage at 60°, 70°, 77°, 90°, and 100° F. in all cases where moisture contents were above 14 percent. At 60° this increase was small. The rates of growth became greater at higher temperatures. At 90° and 100° they became so rapid that the samples with 15 to 16 percent moisture became moldy masses (31).

When mold populations became large they held considerable moisture, and the hygroscopic equilibria of moldy rice samples became greater than those of rice alone. This in turn hastened deterioration of the rice. The effect generally did not become appreciable until the quality of the rice was already considerably affected. Mold growth plays a large part in the deterioration of rough rice but the extent to which it is primarily responsible for quality loss will require further investigations. In the controlled storage of Caloro rough rice, the mean values for viability, sucrose sugar content, and the logarithms of the free acidity show significant correlations among several individual storage experiments (40).[8]

A study by the Southern Regional Research and Development Division indicated that milled rice produced in the southern part of the United States in 1954 was not normally infected internally by fungi or bacteria (41). Very few rice kernels examined in this study were found to be infected internally.

Factors influencing the deterioration of rice bran during storage were investigated by noting the effect of moisture content on the growth of bacteria and of filamentous yeasts and molds in comparison with its effect on the formation of free fatty acids in the oil (42). That moisture content of the bran was a limiting factor in the growth of microorganisms was demonstrated by the fact that no appreciable growth was observed except in bran which had come into hygroscopic equilibrium, either by gradual absorption or by immediate addition, with relative humidities higher than 62.5 percent. Above this humidity, certain organisms seemed to have optimal conditions for growth when they were present in a mixed culture. Moisture content was a limiting factor also in the formation of free fatty acids. The effects on unautoclaved and autoclaved bran differed. In unautoclaved bran free fatty acids formed at a rapid rate, especially at the higher moisture content. Autoclaved bran showed no increase in free fatty acids regardless of moisture content as long as the sample remained sterile. In autoclaved bran which had been inoculated with A. chevalieri, a similar optimum moisture content as was shown for the growth of the mold in mixed culture was demonstrated by the production of free fatty acids.

Thus moisture had a similar effect upon both microorganisms and formation of free fatty acids and both often increased at the same time in the same sample. The indication of a relationship between the growth of some microorganisms and the formation of free fatty acids is demonstrated by the fact that inoculation of autoclaved bran with A. chevalieri caused the production of free fatty acids. The results of the study support the observations of several observers and demonstrate that the rate of formation of free fatty acids

[8] Also Houston, D. F., and coworkers. Unpublished reports.

is dependent upon moisture; that heating and drying stabilize the bran; that bran will absorb moisture at the higher relative humidities; and that free fatty acids will not be formed in bran which previous to inactivation by autoclaving has been sterilized and is kept in this condition.

More knowledge is needed about the relative parts played in deterioration of rice by microorganisms, particularly molds and yeasts, and by enzymes native to the grain. This information is important in determining the nature and causes of souring, stackburn, heat damage, and other storage problems. More information also should be obtained on the types of organisms present under different storage conditions, the possible progressive changes in their relative amounts, and the effects of individual species or strains upon the properties of the rice grain.

METHODS, EQUIPMENT, AND STRUCTURES FOR CONDITIONING RICE

Conditioning has been defined as those "processes which change the physical properties or state of harvested crops to maintain or improve market quality or storability." Research on conditioning rice has been carried on at the State agricultural experiment stations in Arkansas, California, Louisiana, and Texas and by four research divisions of the U.S. Department of Agriculture--the Agricultural Engineering Research Division and the Southern and Western Utilization Research and Development Divisions of the Agricultural Research Service, and the Marketing Research Division of the Agricultural Marketing Service. Each of these groups has tended to emphasize specific phases or has employed a different approach to the same phases of the problem so that the work is complementary. In some instances, as the following discussion indicates, duplication of tests has been desirable where regional differences are encountered in rice varieties, climatic conditions, cultural and handling practices, or industry procedures. No single set of recommendations for conditioning rice will apply in all of the rice areas of the United States. These differences are reflected in the findings reported by the several research units involved.

Currently studies in Arkansas seek to determine the effects upon the quality of rice of variations in moisture, temperature, and time during the drying and storage process. The objectives of this work are to reduce the amount of checking in conditioning and drying processes and thereby increase the market value of rice, and to reduce the time required to condition and dry a lot of rice to minimize any possible storage damage during drying and subsequent to drying. In a second project relating to the effect of drying pack thickness upon head rice yields and germination, it is hoped that more information may be obtained on the maximum and minimum thickness for drying pack or bed where rice is moving and where it is static. In Louisiana, emphasis is on the determination of causes and remedies for checking and breaking of kernels, more efficient harvesting methods, and the development of low cost farm driers and farm storage facilities. Texas is directing attention to using unheated air and supplemental heat in drying and storing rice on farms. More adequate data are sought on the effect of different airflow rates through stored rice of different initial moisture contents and at various depths on the rate of moisture removal, power needs, germination, infestation by microbiological organisms, fat acidity, and milling quality. This information will provide a basis for modifying present air distribution systems for maintaining a more uniform air distribution throughout the rice mass and a basis for revising operating procedures for drying rice on farms.

In the U.S. Department of Agriculture, the Agricultural Engineering Research Division of Agricultural Research Service is engaged in basic studies the findings of which are applicable to rice as well as to other grains. Through these investigations it is hoped to gain more knowledge of the moisture content at which grains come to equilibrium under different conditions of relative humidity, a more satisfactory explanation of the way moisture leaves grain during drying, and the relation of duct design to efficiency of air distribution. The Western Utilization Research and Development Division is evaluating the application in commercial plants of improved drying procedures based upon laboratory findings of studies related to drying characteristics of rice. The transition

from the laboratory scale to full scale commercial operation has been successful for western rices and now is being studied in reference to varieties and conditions common in the southern rice area. Engineering research underway in the Marketing Research Division of Agricultural Marketing Service includes work on rice aeration, drying and handling problems in commercial facilities in the South. Studies are being made on the effect of drying temperatures, number of passes through the drier, use of aerated storage in connection with drying, and the relationship of these variables to milling quality and other quality factors. Additional investigations concern improved design of aeration systems in commercial facilities and variations in method and operating procedures for aerating with mechanical systems of different designs.

Principles Involved in Conditioning Rice

Two basic processes or principles are involved in conditioning rice--drying and respiration. When rice dries a moisture gradient soon develops, with the center of the kernel being at a higher moisture content than the part of the kernel near the surface. The rate of moisture movement from the high moisture central part to the surface where it is removed from the kernel determines the drying rate and the in-drier time for a specific drying job. When partially dried rice is removed from its drier and stored, the moisture equalizes in each kernel. The equalization process moves some of the moisture from the center of the kernel nearer the surface where it is more easily removed when drying is resumed. Thus, the "pass" procedure used for drying rice permits the job to be done in a reduced time and minimizes checking and subsequent breakage in milling by reducing the internal stresses caused by differences in moisture levels between the outer and inner portions of the kernel.

When the drying air travels any significant distance through the drying rice, the moisture liberated by the rice raises the humidity and lowers the temperature of the drying air. Each of these effects reduces the rate of drying of the rice, and a drying front moves slowly through the mass in the direction of the air movement. The part of the rice where the air enters loses moisture rapidly. The moisture content of the air leaving the rice mass may be so high at the beginning of the drying period that drying cannot take place for some time. Spoilage where the high humidity air leaves the mass may take place at the rice surface if the relative humidity is over 85 percent and temperature above 60° F. (16). Increasing the air rate through the mass will decrease the total drying time, eliminate the possibility of surface spoilage, and reduce the moisture content range when the mass has dried adequately.

Schmidt and Hukill (57) studied the effect of temperature and relative humidity on head yield and reported that loss in head rice yield during drying depends upon the saturation deficit and rice variety. Henderson (17) in a similar study observed comparable results. Unpublished data[9] at Crowley, La., indicate that air temperature alone has little effect on the milling quality of rice dried in a Louisiana State University type drier, providing other variables are controlled. Various saturation deficits and vapor-pressure differentials were determined by Wratten and coworkers[9] in Louisiana as indicative of suitable drying conditions for obtaining optimum milling yields. Temperatures as high as 185° F. were used in the LSU type drier along with various relative humidity values. The amount of moisture removed in each pass, along with the temperature of the rice, might well be a close criterion for drying rice to be milled. No such limits have been established to date, although additional study of this factor is in progress. The additional length of time that samples are subjected to certain vapor-pressure differentials in air has been explored by Wratten and coworkers and currently at Albany, Calif., is being studied by Wasserman and coworkers.[10]

Clean dry rice stored at a recognized safe moisture content (13.5 percent) may spoil while in storage from the products of respiration, a natural process for all living grains. The rate of this process and the products resulting from it are given for rice in Figure 11 (3). The process is self-accelerating since both the moisture and heat which are

[9] Wratten, F. T., and coworkers. Unpublished data on dielectric treatment of rough rice.
[10] Wasserman, T., and coworkers. Unpublished data.

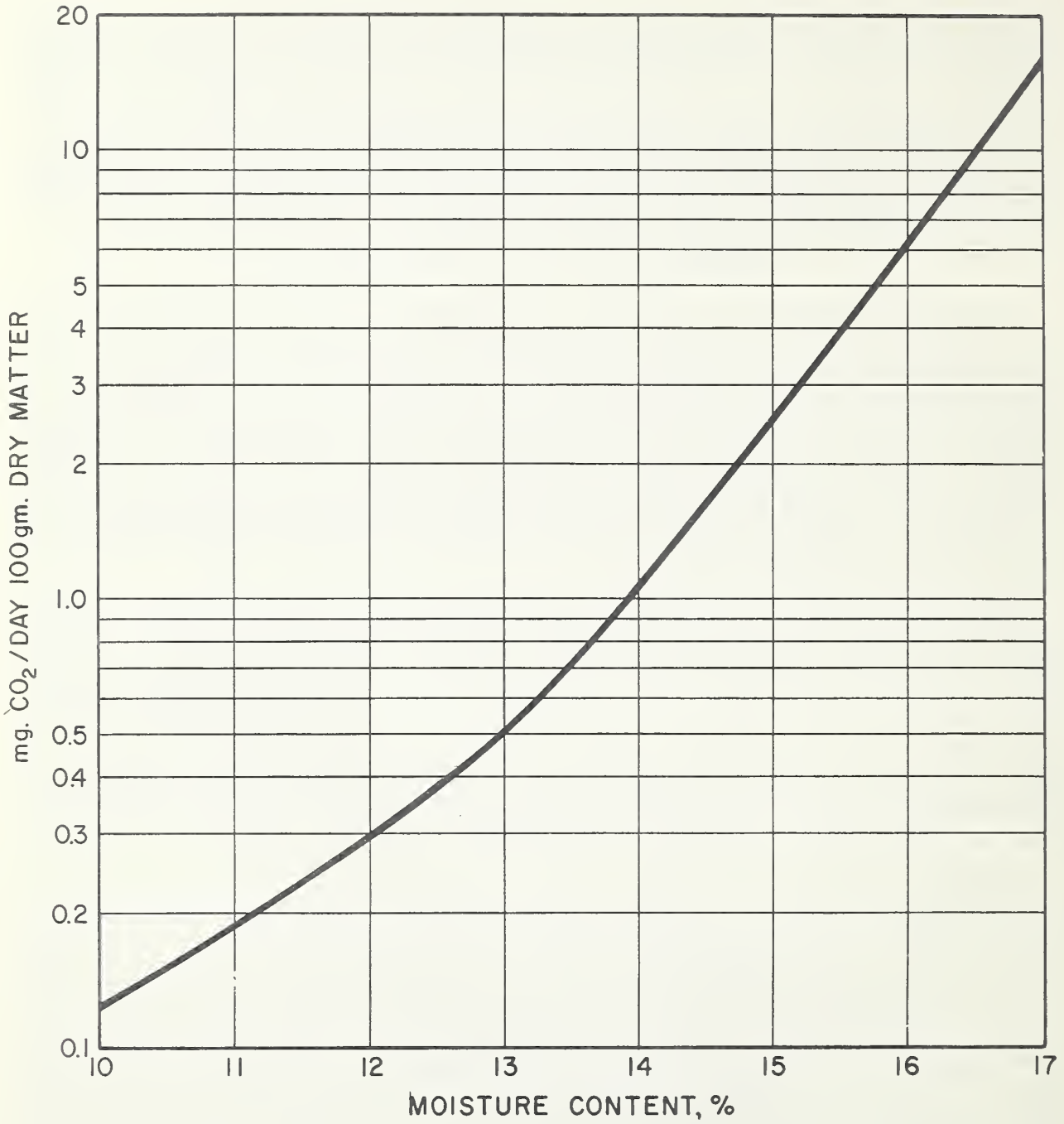

Figure 11.--Respiration of rice at 100° F. The rate approximately doubles for each 20° increase in temperature.

produced increase the process rate. The CO_2 that is produced tends to reduce or modify the process if sufficient quantities can be accumulated. Additional information is needed on this phase of the process.

Problems Faced by the Drier Operator

The chief aim of the operator of a rice drier is to reduce the moisture content of the freshly harvested rice to safe storage levels with the minimum feasible loss in

quality. He is restricted in his choice of operating conditions by permissible operating costs, characteristics of his plant equipment, and urgency of drying before spoilage takes place.

Rice is primarily consumed in the form of unbroken kernels. The number of pounds of unbroken rice that can be milled from 100 pounds of rough rice is known as the head yield. The number of pounds of all rice (broken plus unbroken) milled from 100 pounds of rough rice is known as the total yield. Both head and total yields are expressed in pounds or on a percentage basis. As the market value of unbroken kernels is greater than that for broken kernels, the drier operator seeks to avoid conditions that promote breakage during the drying process.

The fact that the rice crop matures and is ready for harvest during a relatively short time period leads to heavy demands on rice drying plants. Weather conditions have a pronounced effect on the efficiency with which available facilities may be utilized by the operator. In damp weather, when the rice dries slowly in the field, it usually is harvested at a high moisture content and is subject to rapid spoilage. The drying plant operator is then called upon to dry the rice in as short a time as possible and also must remove more than the normal moisture from the rice while operating under the handicap of high humidity air. In hot and windy weather the rice may dry too rapidly in the field and deteriorate because of checking. Efforts to avoid this damage also result in heavy deliveries in a short interval to the drying plants. The operator is faced not only with demands from growers, but also must turn out rice of acceptable milling quality. Considerable judgment must be exercised by the drying plant operator to provide maximum returns for all concerned.

Holding Undried Rice

The moving of air at low airflow rates through undried rice with moisture content from 18 to 24 percent has proved effective for periods of a week or 10 days in preventing spoilage. Tests made in Arkansas show that 1 cubic foot of air per minute per bushel was adequate for this purpose (65). Similar results have been obtained in Louisiana. For short time storage of partially dried rice, one-fourth cubic foot per minute per bushel was adequate. The quality of rice with moisture content below 16 percent was maintained for several months in either cool or warm weather with the aid of aeration. In tests made in Texas 1 lot of undried rice at 20 percent moisture was held for 18 days with aeration at an airflow rate of 1/4 cfm per bushel; another lot at 16.5 percent moisture was held for 30 days with an airflow rate of 1/2 cfm per bushel.

Studies made in California show that by using adequate aeration, rice with moisture content over 18 percent can be carried through the wet winter period without quality reduction or a decrease in viability (16). Spoilage organisms are dormant below approximately 75 percent relative humidity and 60° F. Since either relative humidity or temperature are usually below these values during winter, spoilage cannot normally be expected even if no drying occurs. Continuous fan operation will aid in keeping the temperature low and therefore seems advisable, except during periods when it is foggy or raining, at which time too much moisture may be drawn into the rice mass.

Bulk Drying of Rice

When too much moisture is removed at too fast a rate, checking or shattering of rice kernels results. To reduce this effect, rice is dried with air at 100° to 130° F. in two or more stages, with each stage involving a pass through the drier. Air temperatures of 140° to 165° have been used successfully with two or more stages in Louisiana.[11] Between drying passes the rice is held in a storage bin until the moisture equilibrates throughout the individual kernels. This step, called tempering, relieves stresses and strains and facilitates drying in the next pass.

[11] Bond, N. J., Jr. The Design and Operation of a Farm Size Grain Dryer. 1951. [Master's thesis. Louisiana State University.]

Observations by Wratten[12] in Louisiana indicate that a continuous gain in drying efficiency occurs when tempering up to 24 hours. The gain is very rapid during the initial 6 hours. The increase in efficiency is at a slower rate during an additional 6 hours and only a minor gain is obtained by additional tempering up to 24 hours. Similar findings are reported in tests of tempering western rice by the Western Regional Research and Development Division (66). Vapor pressure measurements show that short-grain rice (Colusa 1600) which was rapidly dried in 1 pass to give a steep moisture gradient within the kernels was completely tempered in about 12 hours at 90° F. About 90 percent of the total vapor pressure change took place in 6 hours. To determine what tempering time is adequate for practical purposes, rice also was dried in 3 passes with 110° air with tempering periods of 0, 4, 8, 16, and 32 hours at rice temperatures of 105° and 75°. It was found that rice was adequately tempered in 4 hours at a rice temperature of 105° and in 6 hours at 75°. Criteria for adequate tempering were drying time and loss of head yield in the next pass. No appreciable differences were found among storage characteristics of this rice which could be attributed to differences in tempering treatments.[13]

Types of Driers

Commercial drying of rice usually is performed in continuous flow driers similar to those used for other small grains (72). Rice is usually fed in at the top and flows through the drier by gravity. Rate of discharge is mechanically regulated at the bottom. Drying is accomplished by forcing air--preheated in most installations by oil or gas burning directly in the airstream--through the rice as it passes downward.

Rice driers can be divided into two types, depending on whether or not rice is mixed as it passes through the drier.

The nonmixing, columnar drier (Fig. 12) is the simplest. In this drier rice descends between two parallel screens usually set about 6 inches apart, while heated air is blown through the screens and intervening rice. No appreciable mixing occurs, and the effect is similar to drying in a static bed with a bed depth equal to the distance between the screens.

Mixing types of driers are of many designs, two of the most popular being the baffle design and the Louisiana State University design (43, 73). In the baffle drier (Fig. 13) rice is conducted downward in a zigzag path by means of baffles as heated air is forced through the grain. The Louisiana State University drier (Fig. 14) consists of a bin in which layers of air channels are installed. Heated air is introduced at many points in the descending rice bulk through these channels, whose cross sections are shaped like inverted "V"'s. (One end of each channel has an opening, and the other end is solid.) Alternating layers are air inlet channels and air outlet channels. In the inlet layers the openings face the air inlet plenum chamber; in the outlet layers openings face the exhaust. Thus, air is forced to pass through the descending rice in moving from inlet to outlet channels. Each layer is offset so that the tops of the inverted "V"'s split the stream of rice, causing some mixing action.

The amount of mixing that takes place in mixing-type driers is unknown. However, unlike the nonmixing, columnar drier in which the rice closest to the inlet air is always exposed to the highest temperature air, all kernels of rice in mixing-type driers are exposed to air of similar temperature and humidity as they flow downward. A few driers have a cooling section below the drying section, and cool the rice after each pass.

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[12] See footnote 9.
[13] See footnote 10.

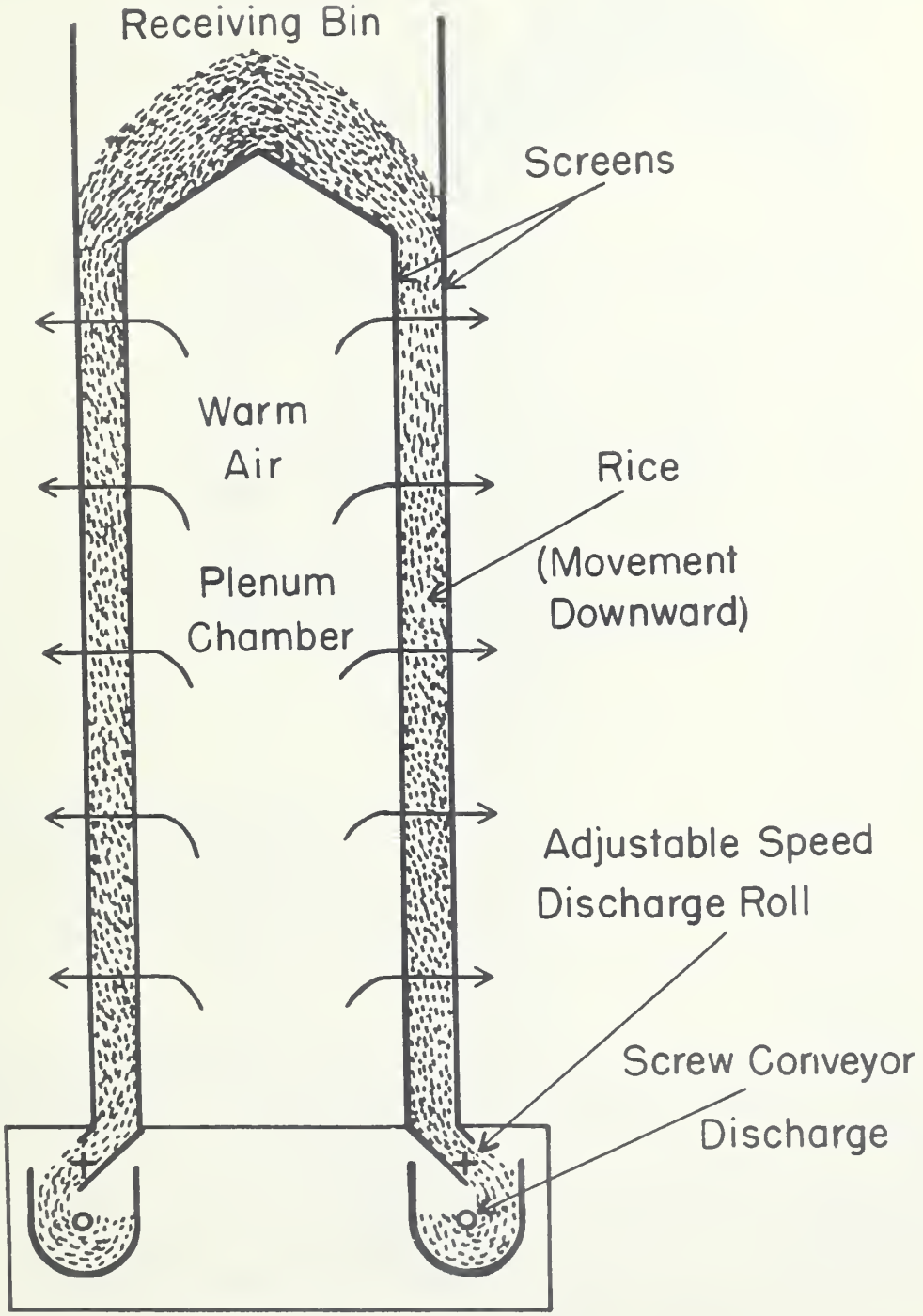


Figure 12.--Nonmixing-type columnar drier.

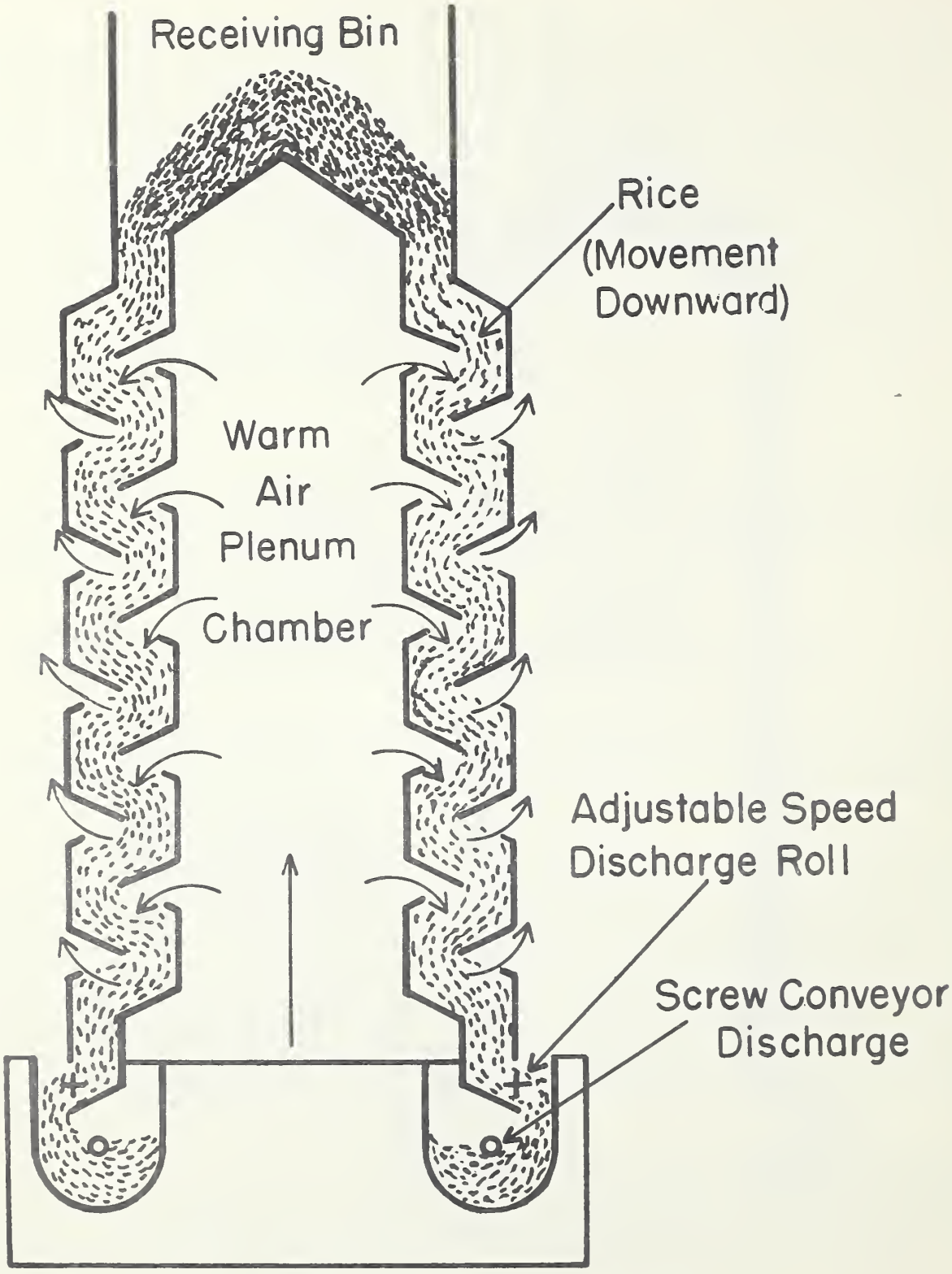


Figure 13.--Mixing-type columnar drier with baffles.

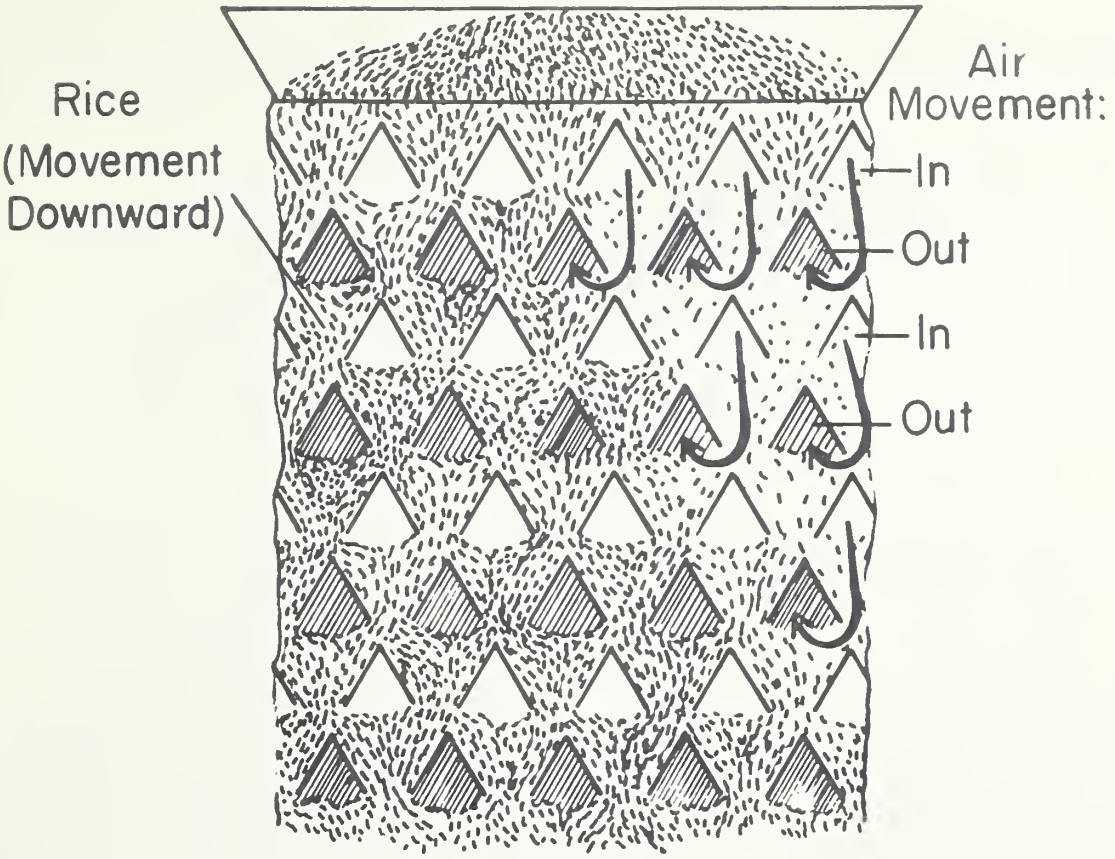


Figure 14.--Flow pattern in LSU mixing-type drier.

Head Yield and Temperature

Laboratory-scale studies have been carried on in California to determine optimum conditions for commercially drying western-grown rice and to provide information to drier operators in a form that may be used regardless of the type of equipment available at the plant. These tests include determinations of the effects of airflow rate, air temperature and humidity, and number of drying stages or passes through the drier on yield and drying time.

The tests, which were performed in 2-inch-deep static beds on 2 short-grain rices, Colusa and Caloro, showed how temperature of drying air and number of passes through the drier affect head yield and total drying time (66, 70-72). The relationship of these four factors can be represented on a single diagram to serve as an operating guide in the drying of rice. Figure 15, containing results obtained when the Colusa variety was dried from 23.6 to 13.0 percent moisture, is such a diagram. It tells an operator what will happen if changes in drying procedure are made, and what methods of operation will bring greatest returns, depending upon whether plant capacity or high head yield is the factor of greatest importance under prevailing circumstances. The three curves (solid lines) on Figure 15 show the effects of different air temperature on total drying time for 1-pass, 3-pass, and 5-pass drying. Broken lines join points on the 3 curves that give the same head yield. The overall trends are basic for rice, as shown by extensive tests on western rice and limited tests on southern rice. Numerical values will differ with variety of rice, season, type of drier, depth of rice bed, amount of mixing in the drier, air velocity as related to bed depth, initial moisture content of the rice, and other factors. The diagram shows that (1) when drying air temperature is raised without increasing the number of passes, drying times and head yields are decreased; (2) when the number of passes is increased without changing the air temperature, drying times are decreased

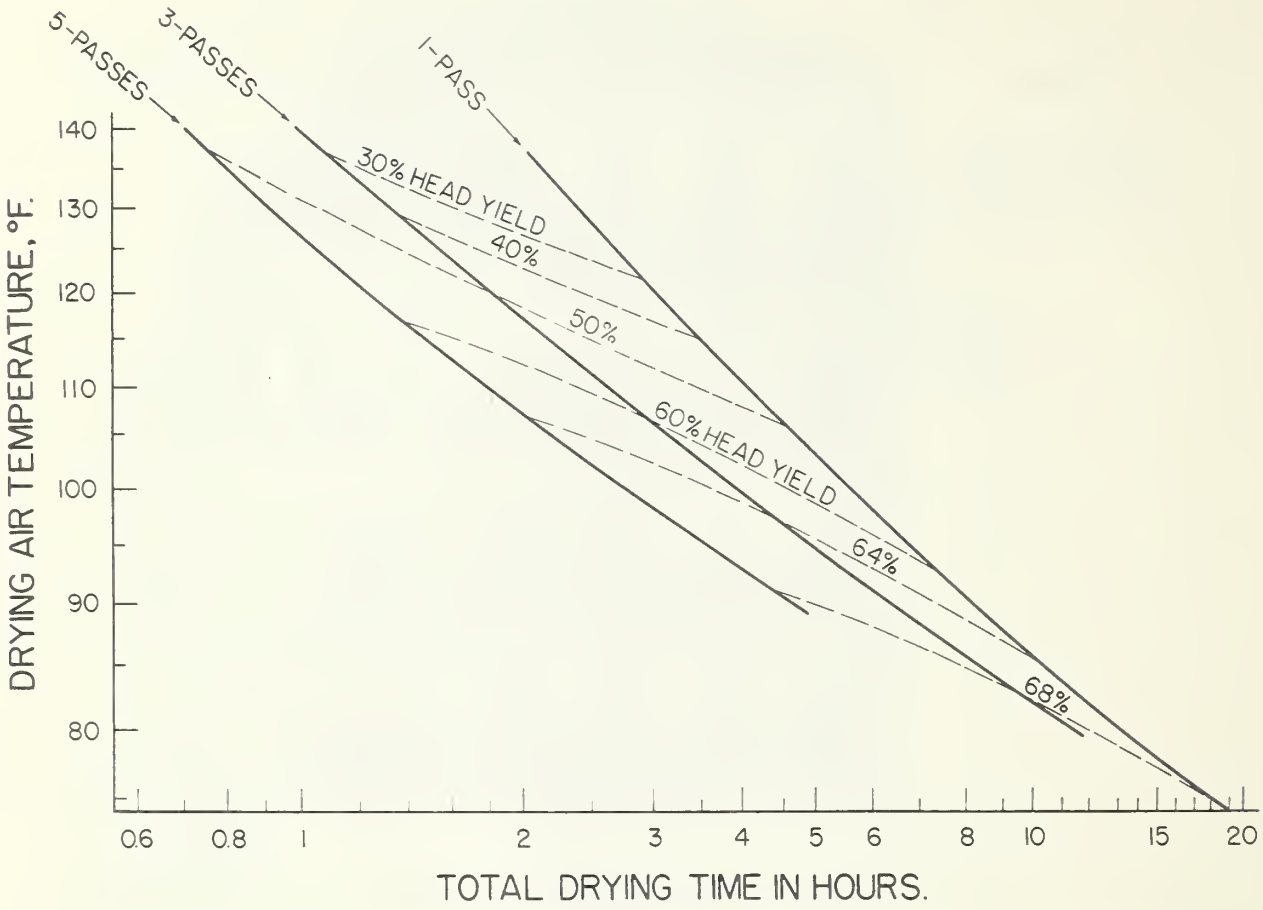


Figure 15.--Effect of drying air temperature and number of passes on head yield and drier capacity (total drying time).

and head yields increased; (3) the combination of high air temperatures and a large number of passes through the drier will give best results if the combination is correctly chosen. Methods for determining the best combinations have been published (73).

A survey of more than 50 driers in Texas shows that there is little consistency in the drying temperatures used by the different firms (34). It also shows that there is considerable variation as to the number of passes through the drier, method of tempering, and moisture content for storage. These findings, together with commercial drying tests and observations made in plants in California, show that there is no single recommendation that will fit all plants and situations. Correct operation for a particular plant is determined by such factors as drier type and size, bed depth, prevailing humidity, quantity of air and velocity through the drier, tempering and storage space, and capacity of conveying equipment. It is therefore necessary for each drier operator to determine the most favorable drying conditions for his plant.

The drier operator is severely handicapped in most plants because he does not know (1) whether he is damaging the rice during drying, and (2) how changes in drying conditions will affect milling yields and drying time. Milling quality can be lowered in the field before harvest or in the drier. To find where damage occurs, the operator must

know the milling quality of the rice he starts with as well as that of the dried grain. Milling yields of rice leaving the drier after each pass will show if any damage has occurred in the drier.

The key to improved drying is a practical method for determining the milling quality of rice at any point in the drying process. In the West, a sample can be taken at any point, dried with air at 75° F. so that little or no damage occurs, and tested for milling yield. The milling yield of this sample, for all practical purposes, is the same as that of the rice at the point where the sample was taken. In the South, where temperatures as low as 75° are rarely found during the drying season, satisfactory results have been obtained in the sample drier by drying for short intervals with air at 110° and then tempering between drying cycles. To accomplish desired results a repeat cycle timer was added to the sample drier during tests conducted in Louisiana. This timer turned the sample drier on for 5 minutes for medium-grain and 3 minutes for long-grain rice, and turned the drier off for periods of 30 minutes between drying cycles.

A simple method was developed that would enable a drier operator to find the best drying conditions for his plant. The method requires no extra help and only a small amount of additional equipment. Descriptions of such equipment and step-by-step instructions for its operation are available from the USDA (Western Regional Research and Development Division) (73).

It has been demonstrated in two modern drying plants that these laboratory-scale experiments could be applied successfully on a commercial scale. The first of these demonstrations was made during the 1955 season at the Sutter Basin Growers Cooperative at Knights Landing, Calif. The driers used were of mixing type of the LSU design and had a minimum bed depth of $12\frac{1}{2}$ inches. After a test run following the usual plant procedure, changes that might lead to higher plant capacity and milling yields were determined by use of the 4-variable diagram (Fig. 15) developed from the laboratory tests described above. Six plant runs were then made on Caloro rice employing these changes. The results are summarized in Table 7. Tests 2 and 3, which gave the best results, show that by increasing the rate at which rice is passed through the drier from 1,260 to 1,760 cwt. per hour, by increasing the temperature of the drying air from an average of 119° to 137° F., and by using 1 extra pass through the drier, plant capacity was increased 58 percent, drying costs were reduced $1\frac{1}{2}$ cents per cwt., and head yield was increased $2\frac{1}{2}$ percent and total yield $1\frac{1}{2}$ percent. These increases were made without a decrease in viability (73).

The second demonstration was made during the 1956 drying season at the plant of the Farmers Rice Growers Cooperative at Sacramento, Calif., using nonmixing columnar driers with a 6-inch distance between screens. Results are shown in Table 8. Increasing the feed rate, temperature of drying air, and number of passes increased plant capacity by 37 percent and reduced costs by 1 cent per cwt. As in the first case, there was no decrease in viability, but head yield decreased 1.4 percent and total yield 0.4 percent compared with the customary method of operation at this plant (74).

Temperature of rice as it leaves the drier is used by some operators as a method of determining the safety of the drying conditions employed. Air temperature and length of time in the drier are controlled so that the rice leaving the drier does not exceed a certain temperature. Data obtained from the tests on 2-inch beds of rice show that rice temperatures have only limited value for such control. Three distinct curves were obtained for 1-pass, 3-pass, and 5-pass drying when final rice temperatures were plotted against final head yields (Fig. 15). For example, a rice temperature of 105° F. at finish of drying was found to correspond to 23 percent head yield for 1-pass drying, 47 percent for 3-pass drying, and 62 percent for 5-pass drying. Bed depth also has some effect. A

TABLE 7.--Effects at Sutter Basin (Calif.) of changes in drying air temperature and number of passes (feed rate)--mixing-type driers, 1955

Item	Test No.		Average of tests	Average of tests
	1	4	5 and 6	2 and 3
Weight of Rice in Test..... Cwt..	3,250	4,200	4,200	4,200
Passes..... Number..	4	3	4	5
Average Feed Rate..... Cwt./hr..	1,260	960	1,240	1,760
Air Used Per Pass..... Cubic ft./cwt..	3,100	4,100	3,100	2,200
Average Air Temperature..... ° F..	119	135	136	137
Moisture Content of Rice:				
Before Drying..... Percent..	20.1	21.4	21.2	20.2
After Drying..... Percent..	14.2	13.9	13.8	12.9
Head Rice Yield:				
Before Drying..... Percent..	62.9	61.8	61.8	60.6
After Drying..... Percent..	61.8	58.0	59.6	62.0
Total Rice Yield:				
Before Drying..... Percent..	72.1	71.8	71.0	70.8
After Drying..... Percent..	71.9	70.3	71.2	72.1
Germination (viability):				
Before Drying..... Percent..	94	91	94	94
After Drying..... Percent..	94	96	93	94
Time to Evaporate 10,000 lbs. water..... Hours...	6.0	4.2	4.0	3.8
Increases (based on previous drying method (Test 1)):				
Head Yield..... Percent..	0	-2.7	-1.1	2.5
Total Yield..... Percent..	0	-1.3	.4	1.5
Plant Capacity..... Percent..	0	43	50	58

rice temperature of 97° with 3-pass drying gave a head yield of 61 percent in a 6-inch bed and 58 percent in a 2-inch bed. Similarly, a rice temperature of 114° with 5-pass drying gave a head yield of 62 percent in a 6-inch bed and 54 percent in a 2-inch bed (70, 71).

Cooling

Most operators temper the rice at the temperature at which it leaves the drier, and cool it for storage after the last drying pass. A few types of drying equipment have a cooling section below the drying section, and cool the rice after each pass. In the latter group, two methods are used. Cooled air is passed through the rice by means of a separate blower; or atmospheric-temperature air is first drawn through the rice, then air is heated and blown through the rice. Tests show that, unless tempering extends for periods of time which might result in damage to the grain, it is better from the standpoint of heat utilization and drying and tempering times to cool only before final storage. A tempering period should be used between the final pass and storage since this will minimize

TABLE 8.--Effects at farmers cooperative of changes in drying air temperature and number of passes (feed rate)--nonmixing-type driers, 1956

Item	Test No.					
	1	2	3	4	5	6
Weight of Rice in Test..... Cwt..	5,040	3,030	2,420	5,300	5,920	5,880
Passes..... Number..	3	7	6	5	4	4
Average Feed Rate..... Cwt./hr..	990	1,910	1,870	1,920	1,960	1,860
Air Used Per Pass..... Cu. ft./cwt..	3,300	1,700	1,700	1,700	1,600	1,800
Average Air Temperature..... ° F..	117	101	118	129	135	138
Average Rice Temperature Leaving Drier..... ° F..	105	87	97	105	107	107
Moisture Content of Rice:						
Before Drying..... Percent..	19.0	19.0	19.6	19.1	17.5	18.7
After Drying..... Percent..	13.3	13.4	13.3	12.8	11.8	12.9
Head Rice Yield:						
Before Drying..... Percent..	56.4	61.9	60.8	63.5	64.8	64.7
After Drying..... Percent..	54.8	62.4	61.2	61.0	61.5	62.1
Total Rice Yield:						
Before Drying..... Percent..	72.9	74.4	73.6	73.7	75.5	75.1
After Drying..... Percent..	73.8	75.7	75.0	74.4	76.1	75.4
Germination (viability):						
Before Drying..... Percent..	95	92	91	95	92	91
After Drying..... Percent..	97	96	96	97	98	95
Time to Evaporate 10,000 lbs. water..... Hours..	5.2	6.3	4.8	4.3	3.8	3.8
Increases (based on previous drying method (Test 1)):						
Head Yield..... Percent..	0	+2.1	+2.0	-0.9	-1.7	-1.0
Total Yield..... Percent..	0	+.4	+.5	-.2	-.3	-.6
Plant Capacity..... Percent..	0	-17	+8	+21	+37	+37

moisture regain and may permit removal of a small amount of moisture without use of additional heat.

Effect of Moisture Content on Milling Yields

It is well known that rice should be harvested at high moisture contents to avoid field checking and, consequently, lower milling yields. However, the magnitude of the lowering of milling yields is not so well known. To determine this for western rice, every lot of rice received in 1955 at the Sutter Basin Growers Cooperative plant was tested for moisture content and milling yields, and the data were subjected to statistical analysis.[14] Thus, data were available from a number of growers in a small area over the entire harvest season. Ninety-one lots of rice representing approximately 240,000 cwt. of undried

[14] See footnote 10.

rice were tested. Moisture contents ranged from 15 to 20 percent. A summary of data for 84 lots of Caloro and Colusa 1600 is given in Table 9. (Data for the seven lots of Calrose were omitted from the table since they were not statistically significant.) The best results were obtained by harvesting western rice at a moisture content of 25 percent or above as soon as the rice was mature.

TABLE 9.--Effect of moisture content of harvested rice on head yield

Variety and grower	WRRL MILLING TEST		APPRAISAL LAB. McGILL TEST	
	Lots	Head yield change for 1 percent decrease in moisture	Lots	Head yield change for 1 percent decrease in moisture
Caloro:	*Number*	*Percent*	*Number*	*Percent*
All growers....	71	-1.69**	50	-1.39**
Grower 1.....	7	-.46	7	-2.05*
Grower 2.....	8	-2.45		
Grower 3.....	8	-3.53**	7	-1.50*
Grower 4.....	6	-1.96*		
Grower 5.....	8	-2.78		
Colusa 1600:				
All growers....	13	-1.46		

*Significant at 5% probability level.
**Significant at 1% probability level.

In studies made in Arkansas, it was found that the best milling quality resulted from medium- and long-grain varieties of rice if it was harvested when the moisture content was between 24 and 16 percent (65). Germination appeared to increase as the moisture content at harvesttime was reduced. In Louisiana the optimum moisture content for harvesting rice with respect to the milling quality of the dried product was found to be within a narrower range, from 18 to 21 percent. [15]

At Beaumont, Tex., in studies made on long, medium, and short grain varieties, it was found that the best milling quality and germination were noted when the rice was harvested with 16 to 26 percent moisture. [16]

McNeal of the Arkansas Agricultural Experiment Station gives data on combine losses at various moisture contents. Such losses appear to be no greater at the above moisture ranges than at a higher moisture content. A moisture content of 20 percent at harvest is considered optimum for Arkansas.

Bin Drying of Rice

Bin drying refers to the drying of rice in the same bin in which it is to be stored. Bin drying is the most frequently used method for on-farm drying. Drying usually can be accomplished with unheated air, but heating equipment should be available as an insurance for periods of high humidity weather. Unheated air is a term applied to normal atmospheric air without the addition of heat. Supplemental heat refers to heat added to atmospheric air for a limited temperature rise, usually less than 20° F., to accomplish drying within a maximum permissible drying time or to prevent spoilage.

Drying With Unheated Air

Bin drying of rice with unheated air offers some advantages over drying with supplemental heat. Unheated air drying requires less investment in equipment, it reduces fire

[15] See footnote 11.
[16] Kramer, H. A. Unpublished data on maturity quality.

hazards and usually results in more uniform drying of the rice. There are, however, certain specific limitations. One is the uncontrollable weather factor, since the rate of drying with unheated air is dependent on weather conditions. If rice is to be sold soon after harvest, the comparatively long period required for drying with unheated air is a disadvantage. In this case, some other method of drying should be used. If rice is to be held in storage for a period longer than is required for drying with unheated air, the time element is not as important. Considerable supervision over a long period of time is required when unheated air is used as the drying agent. Other important factors determining the effectiveness of unheated air drying are the moisture content and temperature of the rice, depth of rice in the bin, rate and uniformity of airflow through rice, and presence of excessive foreign material (5).

Drying Equipment

The equipment required for bin drying with unheated air consists of a structure for holding the rice, an air distribution system, and a fan, driven by an electric motor or internal combustion engine. Steel, wood, or concrete bins and buildings are satisfactory storage structures for drying rice. The main consideration is to provide a tight structure to prevent leakage of air and moisture through the bin floor and walls.

An air distribution system should be selected that will provide adequate distribution of air throughout the bin. Types of air distribution systems are false floor, main duct with laterals, and single center duct. These are shown in Figure 16. Main duct and lateral systems are satisfactory for both round and rectangular bins and buildings. False floors are better suited for round bins than for larger storage structures. A center duct is limited to use in a narrow building (a width of 16 feet was used in tests) and requires a building with openings in the wall to permit uniform distribution of the air through the rice. A main duct and lateral system or false floor is recommended for farm drying installations.

Centrifugal and axial-flow fans, as shown in Figures 17 and 18, are suitable for bin drying of rice. Centrifugal fans ordinarily used for farm drying have either "forward curved" blades or "backward curved" blades. "Forward curved" fans are lighter and less expensive than "backward curved" fans. However, with the "forward curved" fan there is a possibility of overloading the motor if the fan operates against static pressures lower than those used in the design of the system. This is an undesirable characteristic for bin drying since rice depths vary during the time bins are being filled. A "backward curved" blade fan offers the advantage of a self-limiting horsepower characteristic. This means that the maximum horsepower, for a given speed and air density, is reached in the usual operating range. The practical advantage is that it is unnecessary to provide excess motor capacity beyond that necessary to carry the normal load.

Axial-flow fans used for farm drying are of two types: Vaneaxial and tubeaxial. A vaneaxial fan consists of a fan wheel within a cylinder with a set of air guides either ahead or behind the fan wheel. It is designed to move air over a wide range of volumes and pressures. A tubeaxial fan consists of a fan wheel within a cylinder without air guide vanes, as shown in Figure 18. Its construction is similar to a vaneaxial fan. The tubeaxial fan is designed to move air over a wide range of volumes at medium pressures.

Axial-flow fans designed to operate against static pressures of 3 inches or more usually are suitable for bin drying. The initial cost of these fans is usually lower than the cost of centrifugal fans. Low initial cost together with the small space required and the ease of installation are advantages.

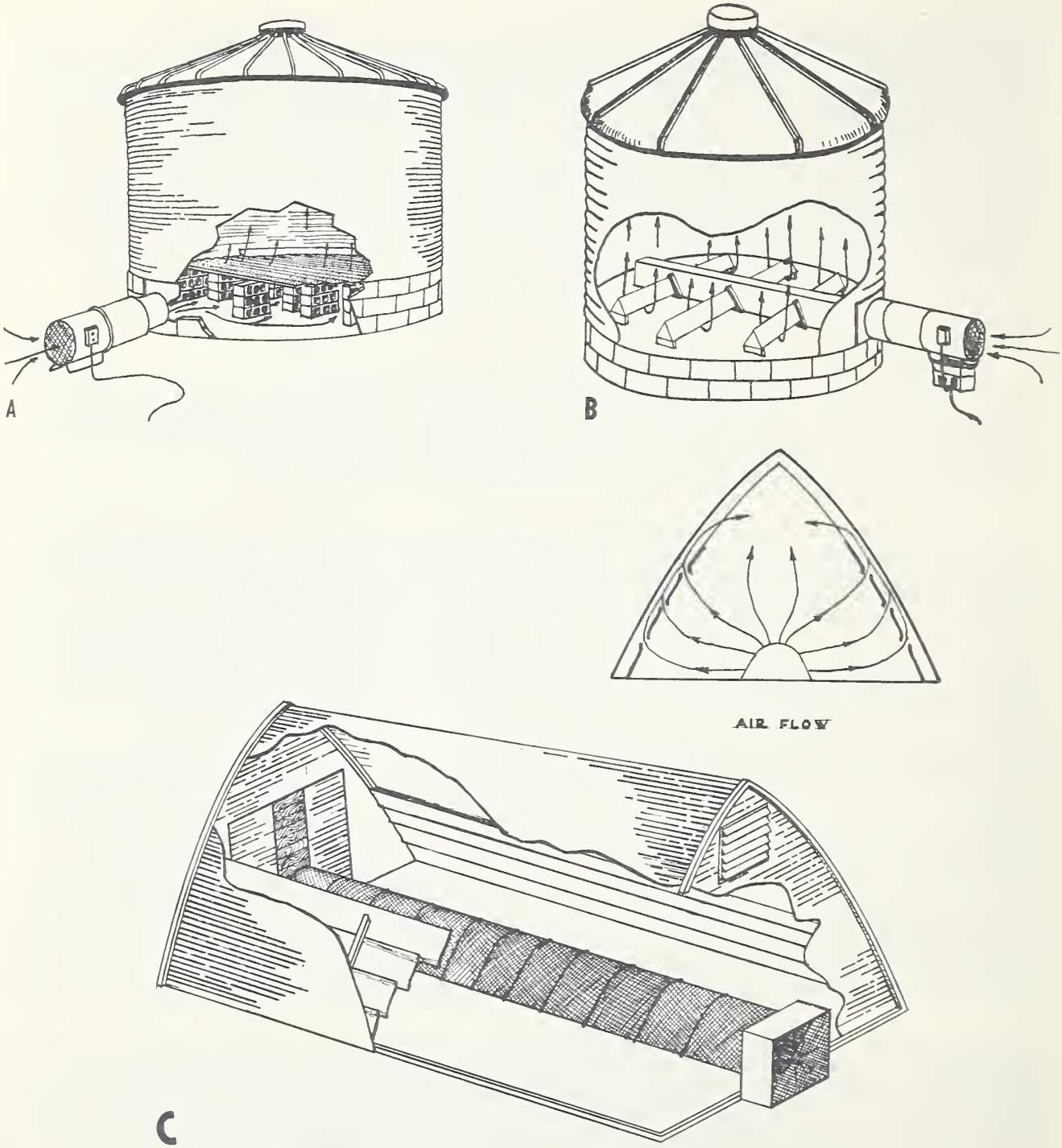
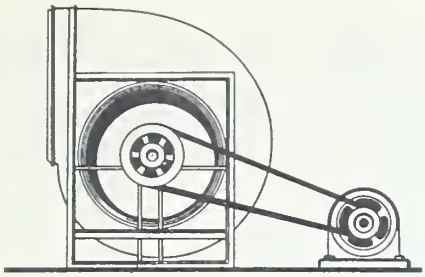


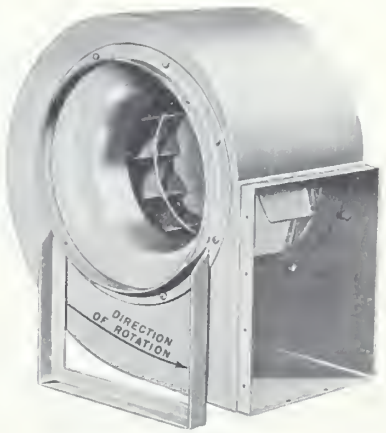
Figure 16.--Types of air distribution systems used in bin drying tests: A, False floor; B, main duct and laterals; C, center duct.



A. Fan wheel equipped with forward curve tip blade.

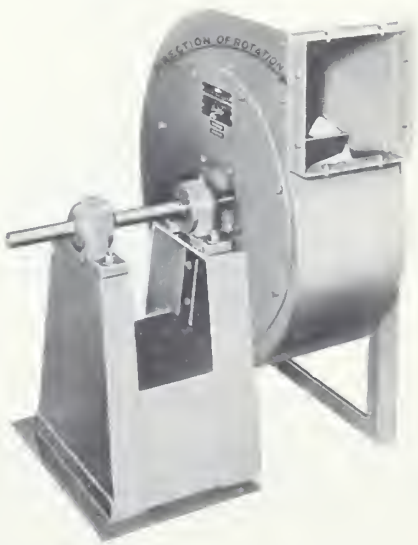
A

B. Fan wheel equipped with backward curve tip blade.



B

C. Fan wheel equipped with straight tip blade.



C

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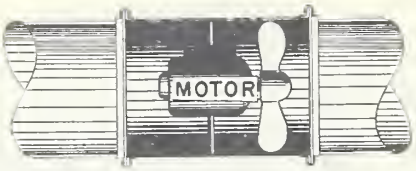
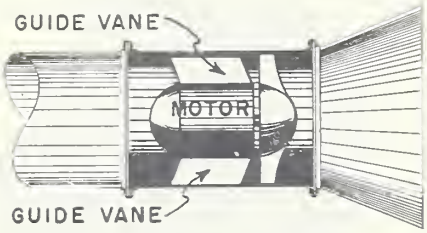
Figure 17.--Centrifugal fan:



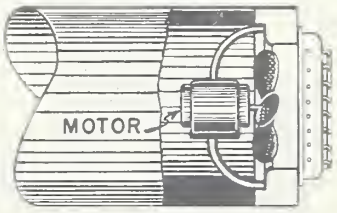
A. TUBEAXIAL FAN

A tubeaxial fan consists of an axial flow wheel within a cylinder. It is designed to move air through a wide range of volume at low to medium static pressures.



B. VANEAXIAL FAN

A vaneaxial fan consists of an axial flow wheel within a cylinder combined with a set of air guide vanes located either before or after the wheel. It is designed to move air over a wide range of volume and pressures.



C. PROPELLER FAN

A propeller fan consists of an axial flow fan within a mounting ring or plate. It is designed to move air over a wide range of volume at low static pressures.

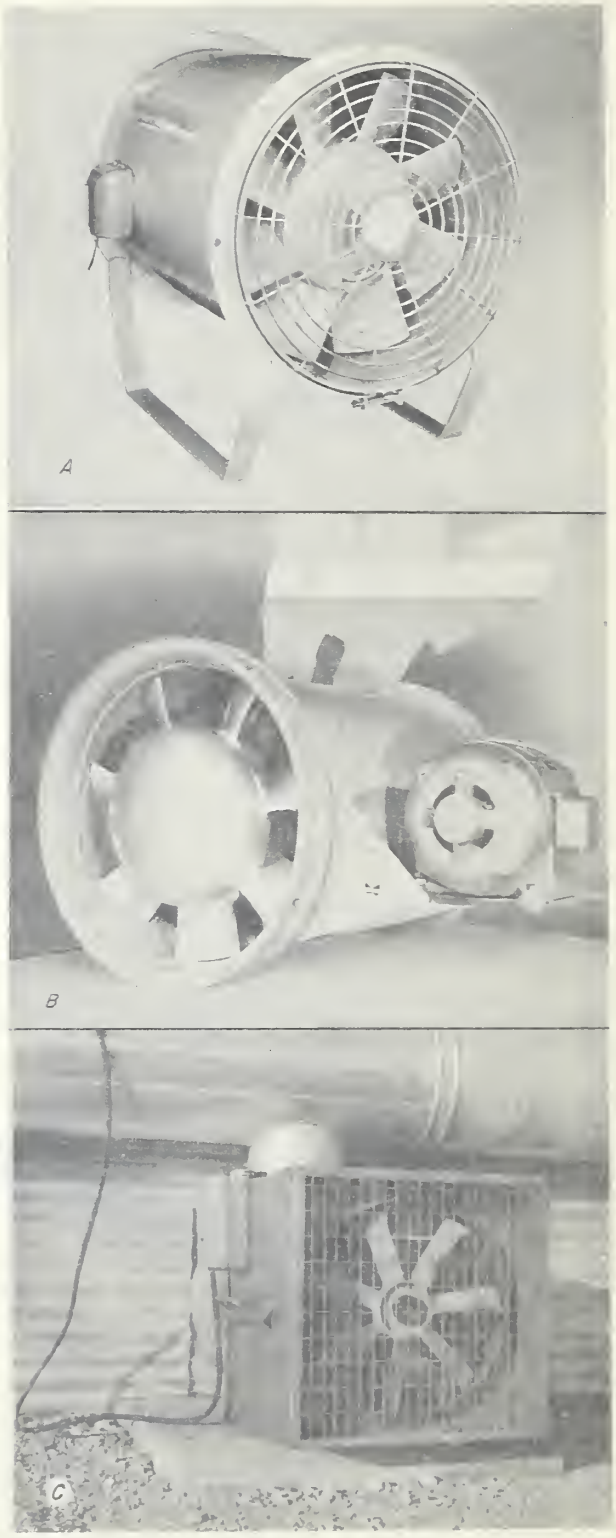


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Figure 18.--Axial flow fans:

Airflow Requirements

The use of the proper airflow rate to dry rice with unheated air is of primary concern. Interrelated with the airflow requirement is the initial moisture content of the rice and the basic drying rate of the rice. Air must be supplied at a rate to complete drying before the rice is damaged by mold growth or other causes. For this reason, the drying rate in the wettest layer of rice provides the basis for selecting the required airflow rate rather than the average moisture observed during the drying operation.

A minimum airflow rate of 7.2 cfm per barrel (2.0 cfm per bushel) was indicated in tests at Crowley, La., and Beaumont, Tex. (62). This rate was based on favorable weather for drying and on rice with a maximum moisture content of 20 percent. However, the rate should be somewhat higher to take into consideration more severe weather conditions and rice with higher initial moisture content. To insure drying without loss in grade and milling yields under the different weather and moisture conditions occurring within a season or from year to year, an airflow of 9.0 cfm per barrel (2.5 cfm per bushel) is recommended for drying rice in Louisiana and Texas. This amount of air is also sufficient for maintaining germination.

Studies to date indicate the optimum rate for the conditions of the central valley of California is between 1 and 2 cubic feet per minute per bushel of rice (2 to 4 cfm per sack) if the moisture content must be reduced to 13.5 percent before December 1 (16). The minimum recommended airflow rate for damp rice stored during the first week of October or earlier is as follows:

	Airflow rate[1]	
	Per bushel	Per sack
Average moisture content at harvest (Percent):	*cfm*	*cfm*
26	2.00	4.00
24	1.75	3.50
22	1.50	3.00
20	1.25	2.50
18 or lower	1.00	2.00

[1]The rate should be increased for rice harvested later than October.

Information needed to select fans for drying rice concerns total air volume required and the static pressure required. Static pressure is a measure of the resistance the air distribution system and the rice offer to the flow of air. It is designated in inches of water. Estimated static pressures through rice for various operating conditions are given in Table 10.

Depth of Rice

The recommended airflow rate of 9.0 cfm per barrel limits the depth of rice to a maximum of 8 feet to accomplish the most economical drying. As stated previously, this rate is based on a maximum moisture content of 20 percent. The moisture content of rice, as well as weather conditions, varies within and between seasons. It is important to provide drying equipment of sufficient capacity to insure drying rice without loss in quality under the different conditions encountered. When the initial moisture content of the rice is above 20 percent or when the rice is harvested late in the season, the depth of rice should be reduced to obtain higher airflow rates needed for the more severe drying conditions. Recommended depths for drying rice at different initial moisture ranges are shown in Table 11. This is based on selection of equipment to provide the recommended airflow rate of 9.0 cfm per barrel at an 8-foot depth with rice at a maximum moisture content of 20 percent. If time of drying and power requirements are not limiting factors, the depth of rice may be increased.

TABLE 10.--Estimated static pressure required to develop different airflow rates through various depths of rice

Depth of rice (Feet)	Static water-column pressure[1] by indicated airflow rate in cubic feet per minute per barrel[2]				
	3.6	7.2	9.0	10.8	14.4
	Inches	*Inches*	*Inches*	*Inches*	*Inches*
4.....	0.30	0.60	0.75	0.85	1.20
6.....	.65	1.10	1.40	1.80	2.60
8.....	1.00	1.80	2.50	3.25	4.35
10.....	1.45	3.00	4.25	5.15	7.25
12.....	1.85	4.80	6.10	7.45	---
14.....	2.60	6.50	8.75	10.75	---
16.....	3.60	8.40	11.50	---	---

[1] Based on data presented by C. K. Shedd (58). The pressures shown include an estimated 0.25 inch pressure drop in duct system.

[2] Airflow rates shown correspond to rates of 1.0, 2.0, 2.5, 3.0, and 4.0 cfm per bushel, respectively.

TABLE 11.--Recommended depths for drying rice with 2 ranges of initial moisture contents in Louisiana and Texas

Initial moisture content of rice (Percent)[1]	Maximum depth of rice at start	Operating procedure
	Feet	
20 to 22.....	6	When the top foot of rice is reduced to 16-percent moisture, more rice may be added to fill to the recommended depths.
16 to 20.....	8	When the top foot is reduced to 15-percent moisture, rice with a moisture content of 16 percent or less may be added to fill the bin to a depth of 10 feet.

[1] A moisture content of 22 percent is the maximum recommended for drying with unheated air.

In California, the minimum recommended airflow rate for drying rice is 1 to 2 cfm per bushel. With these airflow rates, 14 to 20 feet appear to be the maximum practical depth for installations.

Drying Time

Under similar weather conditions, the time required to dry rice with unheated air depends on the rate of airflow, the initial moisture content of the rice, and the uniformity of airflow through the rice.

In drying rice with unheated air under Texas conditions, it appears that the moisture in the wettest layer of rice at temperature of 65° to 76° F. must be reduced to 15 to 16 percent in 15 to 18 days or less to prevent undesirable mold development. Further reduction in moisture to a safe storage level of 12.5 percent can then be accomplished over a longer period of time without loss in grade and milling yields.

Fan Operating Schedule

A primary factor in the selection of a fan operating schedule is the provision for drying at a rate fast enough to prevent mold development. Another important consideration is simplicity of operating instructions requiring a minimum of supervision of the drying operation. Other desirable features in a fan operating schedule are maximum drying efficiency and use of minimum airflow rates.

The direction of air movement is not important as regards general drier performance. A pressure system (air pushed) moves the air upward through the mass. The moisture-laden air is discharged under the roof. Moisture may condense on the underside of metal roofs if there is insufficient under-roof ventilation. A suction system (air pulled) moves the air downward through the mass. The moisture-laden air is discharged from the fan into the outside atmosphere and the roof condensation problem does not exist. However, the wettest grain is near the bottom of the mass and is difficult to sample. It is recommended that air be pushed for the following reasons: (1) After some drying the wettest layer of rice is at the top, where sampling is easily accomplished; (2) heat from the motor and fan can be utilized in drying; and (3) under farm conditions the wettest rice frequently is the first loaded into the bin and the first to be dried.

The following fan operating schedule is recommended in Texas (61): The fan should be started as soon as the air distribution system is uniformly covered with rice and air pushed through the rice continuously until the moisture content of the top foot of rice is reduced to about 15 percent. After the moisture is reduced to this level, the fans should be operated only when the relative humidity is less than 75 percent (usually during daylight hours on clear, bright days). This procedure should be continued until the moisture content of the top foot of rice is reduced to 12.5 percent. The fan should be stopped when heavy rains occur. When rainy periods last longer than 24 hours, the rice may be kept cool by operating the fan 2 to 3 hours each day until the weather clears.

In California it was found that the fan should be operated continuously except during heavy rains and dense ground fogs (18). If the maximum moisture content is 15 percent or less and it is later than the third week of October, operate the fan only when the sun is shining. When heating or mold development is indicated or suspected, operate the fan irrespective of weather until the unsatisfactory conditions have been corrected.

Filling Bins

Faster drying can be accomplished by filling bins in layers. Each bin may be loaded with rice to a depth of 2 to 3 feet in succession. Then, starting again with the first bin, 2 or 3 feet of rice are added to each bin progressively. Two or more progressive fillings may be made until all the storage space is utilized.

With this procedure, the maximum fan capacity can be used for the wettest rice. This will result in faster drying and reduce the possibility of damage from molds.

Sampling for Moisture Content

The moisture content should be checked at least twice a week during the drying operation. The rice should be probed at 8- to 10-foot intervals over the surface of the rice and samples drawn from the bottom, center, and top foot.

Since low temperatures during drying do not always indicate that rice is in good condition, the samples pulled for moisture content also should be checked for mold growth.

Use of Supplemental Heat

Bin drying with supplemental heat has the following advantages and disadvantages. The chief advantage is the fact that drying can be accomplished regardless of weather conditions and a further advantage may be the comparatively shorter drying time. Possible

disadvantages include overheating the rice, which may result in overdrying and loss in quality; the higher initial equipment costs; the close supervision required; and the fire hazard. A structure for holding the rice, a fan, and an air distribution system as described for bin drying with unheated air are satisfactory for bin drying with supplemental heat. In addition, a heating unit is required to heat the air to the desired temperature.

Electric and gas heaters were used in tests conducted by the Louisiana and Texas Agricultural Experiment Stations (60). An electric heater has some advantages that make it attractive to producers as a source of supplemental heat. Electricity provides a clean source of heat, and controls are readily available and easy to install for automatic operation. However, an electric heater has the following disadvantages: It is expensive to operate; it necessitates increased wire and equipment sizes to take care of increased electrical loads when the heaters are used; and it creates high-peak, short-duration loads, which may be undesirable in some areas.

Natural or LP gas is a satisfactory source of heat in most areas. One or the other of these gases is readily available to the farm; the burners are inexpensive; the operating cost is reasonable; and simple, inexpensive controls can be installed to cut off the gas supply automatically in case of flame, fan, or power failure.

A semiautomatic gas heater adjusted to provide a fixed quantity of heat was found satisfactory for bin drying of rice in Texas (60). The variation in output by the burner was controlled by the size of orifice used and/or by opening or closing a gas-cock valve. "Semiautomatic" refers to a burner that must be lighted and turned on manually but is equipped with safety controls to automatically cut off the gas supply in the event of flame or power failure.

A semiautomatic heater, as described, could be made to operate automatically by using a pilot burner and a humidistat set to control the operation at the desired humidity range. With a burner adjusted to provide a fixed quantity of heat, the atmospheric humidity, rather than the humidity of the drying air, could be used as a basis for operating the heater.

The following is a summary of recommendations developed from tests in the southern rice area and in California.

Supplemental heat is not recommended as a standard practice for bin drying. However, it is desirable to have equipment available for use during periods of adverse weather. This will normally be during prolonged periods of high humidity (above 75 percent). The temperature of the air entering the rice may be riased 10° to 15° F. above the ambient temperature. A maximum of 95° is recommended by Texas and a maximum of 80° to 85° by California. Supplemental heat should be used until the moisture content of the top foot of rice is reduced to 15 percent. After the moisture is reduced to this level, use unheated air to complete the drying to a safe storage level. During the time unheated air is used, operate the fan only when the relative humidity is less than 75 percent, which will be usually during daylight hours on clear bright days.

Sack Drying of Rice

A sack drier is particularly suited for drying seed rice to prevent mixing of varieties. It is suitable for drying a small quantity of rice, but it is not applicable where a large amount of rice is to be dried. The chief disadvantages to this type of drier are the high labor and equipment costs involved in sacking and handling the rice, the low drying capacity, and the close supervision required.

Tests were conducted for 5 years at the Rice Pasture Experiment Station, Beaumont, Tex., to determine the effects of the temperature of the drying air and the volume of air used on the rate of drying, milling quality, and germination of rice dried in sacks (65). Bluebonnet, Texas Patna, Rexoro, and Century Patna varieties were dried. It was found that high milling yields of head rice and good germination were obtained with use of a maximum air temperature of 110° F. The fastest rate of drying was obtained with an

air volume per sack of 200 cubic feet per minute for large sacks (160 pounds of dried rice) and 140 cubic feet per minute for small sacks (110 pounds of dried rice). The static pressure requirements under these conditions are 1.70 inches for the large sacks and 1.25 for the small sacks. Turning the bags of rice once during the drying operation gave best results. A slightly higher capacity was obtained by using small sacks. Small sacks also are easier to handle. An 11- by 24-inch sack opening was most suitable for the large sacks and a 9- by 22-inch opening for the small ones. The center-to-center spacing required for the large openings was 26 inches, for the small ones 19 inches. There was no significant difference in the rate of drying of the varieties used in these tests.

Plans for sack driers are available from the California Agricultural Experiment Station, Davis, Calif., and the Texas Agricultural Extension Service, College Station, Tex.

Dielectric Drying of Rice

Tests carried on in Louisiana using radio frequency within the range of 5 to 40 mc. as a source of heat for drying rice indicate that this method is not feasible from the standpoint of cost.[17] The initial cost of equipment is excessive when compared with the cost of conventional drying equipment. However, operating costs compare more favorably with those of present commercial drying methods.

The principal advantages expected from the use of dielectric heat are more uniform application of heat throughout the rice mass and more rapid drying of the rice compared to conventional systems. Three passes of only 5 minutes each were required to reduce the moisture content of the rice from 21 to $13\frac{1}{2}$ percent.

Since these tests were limited to a narrow range of frequencies as a source of heat, it cannot be concluded that dielectric heat may not in the future be feasible for the drying of rice. Additional research is needed in this field before definite conclusions can be reached.

METHODS, STRUCTURES, AND EQUIPMENT FOR STORAGE OF RICE TO MAINTAIN QUALITY

Bulk Storage

Following harvest and drying, rice is generally stored as rough rice in bulk storage bins. These bins may be located on the farm where the rice was produced, at a commercial drier, or at a mill. The length of the storage period for rice depends upon market conditions, but it is usually from 5 to 8 months.

Whether in farm type bins, flat storage, or deep storage, observations have not shown any superiority or inferiority of any particular materials of construction. Any construction material is satisfactory if it results in a storage structure that keeps the grain dry, cool, and free of insects and other pests and provides job safety and convenience when one is moving and inspecting the grain. If dried rough rice is to be stored for a few months and longer or if damp rice is to be held prior to drying, the storage should be equipped for aeration.

The most commonly used materials for bin construction are wood, concrete, and steel. These materials appear to be equally good as far as maintaining the quality of rice in storage is concerned.

Steel is the most commonly used building material for flat storages and also for upright storages less than 60 feet tall. Steel has obtained widespread acceptance as a building material for rice bins because it is well adapted for low cost, prefabricated, tight-wall structures.

[17] See footnote 9.

Wooden structures must be well built to be sufficiently tight to prevent seepage of water from driving rains and to hold insecticides or fumigants if they are necessary. Wooden structures generally will cost more to build than prefabricated steel structures and they have the additional disadvantage of being fire hazards. A relatively new type of bin is one built with wood framework covered with corrugated sheet steel or plywood and erected on floor space in warehouses to convert from bag to bulk storage. The main advantage of this type of structure is low initial cost.

Reinforced concrete is used almost exclusively for storage structures with heights greater than 60 feet. Such structures have the advantage of being tight and durable; however, the initial cost is high and it is difficult to adapt these buildings for different storage conditions. They are also more difficult to aerate because of their height.

Relatively small bins are required where rice is stored on an "identity preserved" basis. Sizes commonly encountered for this purpose range from 500- to 1,500-barrel capacity. When rice is "comingled" larger bins are advantageous. The most popular on-the-farm storage in Louisiana consists of a group of round galvanized iron bins having a capacity of 500 to 2,200 bushels per bin. Rectangular metal bins varying from 16 to 40 feet in width and from 60 to 120 feet in length are increasing in popularity in Louisiana because of their wider range of usage. Bin size is important only as it affects economy in overall cost and convenience in operation. Bins of any size will perform satisfactorily if they satisfy the basic requirements.

Moisture content and temperature control the rate of deterioration and infestation in storage. Since the only control of temperature available is by ventilation and depends on atmospheric temperature, the moisture content is the most important single factor in safe storage. Commonly accepted moistures for safe storage are 13 percent for less than 6 months and 12 percent for longtime storage. It has been found that quality of aerated rice below 16 percent moisture can be maintained for several months. Additional research is needed to determine the maximum safe moisture content for longterm storage of aerated rice.

Kester and coworkers (38, 39) compared the storageability of Caloro rice at several moisture levels with and without monthly turning or aeration. The tests were run in experimental 1,000-bushel bins with monthly assay of fat acidity, total and reducing sugars, percent germination, counts of molds and yeasts, and U.S. Grade. They demonstrated that interseed atmosphere results in beneficial effects on the keeping qualities of rice.

It is well established that rice free of dockage can be maintained at a higher moisture content than in the case where dockage is present. In a survey of 70 Louisiana farm bin installations, the high moisture troublesome storage conditions were all found to be directly associated with rice having the highest percentage of weed seed, rice straw nodes, grasshoppers, and other debris. Rice that is very dry (10 to 11 percent) will seldom be attacked by insects; however, insect control measures may be less costly than shrinkage of rice caused by excessive drying. Higher moistures can be tolerated for short periods, particularly if aeration equipment is available for preventing excessive temperatures.

Temperature of stored rice can be controlled to some degree by ventilation. One of the objectives of aeration is to provide uniformity of temperature throughout the mass of grain. Such uniformity is important in preventing migration of moisture from warmer to colder locations in the bin.

Holding rice at any temperature much higher than outside air temperature can cause "sweating" of bin ceiling which may result in a dangerous accumulation of moisture in localized areas.

It has been noted that exposing rice to high temperatures on the order of 100° F. for extended periods of time resulted in loss in viability.

It is well established that insect activity is greatly inhibited at temperatures below 60° F.; thus 60° is a recommended safe storage temperature for insect control.

Mold spreads most rapidly at temperatures around 80° F. and is inhibited to some degree when temperatures are either higher or lower.

It would appear that the best temperature for longterm storage is the coolest which can be maintained. Laboratory studies undertaken on samples of Caloro rice with initial moisture contents of 12 to 16 percent were held for 3 years at -20°, +20°, and +34° F. Quality factors changed very little under the test conditions. Fat acidity showed a definite but slight decrease; viability was somewhat higher in the stored than in the initial samples; mold populations and sugars changed only slightly; and yeast counts fluctuated as the tests progressed and at the end of the storage period showed a decrease from the original value (25).

Turning stored rice or transferring it from one bin to another used to be the only way of equalizing the temperature. During turning little cooling is done, but the warm and cold grain are mixed, with hot spots thus being eliminated. Most operators, by use of aeration, now avoid the expenses of turning, of the extra bin capacity required, and of mechanical damage to the grain resulting from the turning operation.

Aeration of Rice

Aeration is the process of ventilating rice (or other grain) with unheated air for purposes other than drying. Aeration is used primarily for: (1) Holding freshly harvested rice in condition until it can be dried; (2) holding partially dried rice during tempering between passes through the drier; (3) removing harvest or drier heat; (4) maintaining the condition of dried rice in storage; and (5) applying fumigants to stored rice. Although aeration may not completely eliminate all "turning" of stored rice, it can reduce turning to a great extent. Generally the proper use of aeration can maintain the quality of stored rice better and cheaper than turning. Limited data indicate that the total annual cost--including ownership and operating costs--for aerating stored rice may range from about 1/2 cent up to 3 cents per bushel.

Aeration of stored rice tends to prevent storage troubles by reducing and equalizing rice temperatures and by carrying away heat generated in localized areas of the bin where unsatisfactory storage conditions exist. With rice temperatures equalized throughout the storage there is little tendency for moisture to migrate within the rice mass. Moisture migration often causes some increase in rice moisture near cool surfaces.

The quality of rough rice stored in bulk and aerated has been maintained throughout a storage period of 5 to 8 months without turning. The temperature of rice in upright storages has been maintained at 60° F. or below for periods of 6 to 7 months. Under these conditions no additional insect control measures were necessary.

In limited tests at Beaumont, Tex., the use of aeration prior to the initial drying pass and during tempering periods between passes accounted for the removal of 15 to 75 percent of the moisture removed from the rice during drying. One or more passes through the drier appear to have been saved as a result of the moisture removed by aeration. More tests are needed to determine more definitely if the aeration of undried rice and partially dried rice does result in more efficient and economical operation of rice driers.

Immediately after the rice has been placed in storage, aeration to remove the drier heat should be continuous until a "cooling zone" (Fig. 19) has been moved through the rice. Once the drier heat has been removed, the aeration system should be operated when the outdoor air is 10° (F). or more lower than the rice temperature and when the

relative humidity of the outdoor air is below 75 percent. Whenever aeration is started, it should continue--at the same temperature control setting--until the cooling zone has been moved entirely through the stored rice. This cooling zone may be moved through the stored rice in several days, or it may require as long as a month, depending upon weather conditions, airflow rate, and hours of operation.

The minimum airflow rate recommended for the aeration of rice is 1/20 cfm per bushel. Higher airflow rates are desirable in order to complete the cooling more quickly. Use of higher rates makes it possible to be more selective in setting up operating schedules to take advantage of more desirable weather conditions: also, lower rice temperatures are possible. Higher airflow rates are advisable in areas where extended periods of high air humidity prevail. Power requirements and installation costs for aeration systems will be higher as the airflow rate is increased.

In most cases the air is moved from the top of the bin down through the rice and exhausted at the bottom. The main advantage to moving the air downward is that condensation does not take place in the surface layer of rice or on the bin ceiling. Where air has been moved upward from the bottom and exhausted at the top of the rice, condensation has been found to occur both in the surface layer of rice and on the bin ceiling.

In the Southwest with airflow rates of 1/10 cfm per bushel some 90 to 120 hours of aeration time is required in the fall to cause the rice temperature throughout the mass to approach air temperature. At 1/20 cfm per bushel the aeration time would be doubled.

Aeration ducts or collectors are generally installed on the floor of a rice storage. They may be circular, semicircular, arched, rectangular, or of an inverted V- or U-shape. Perforated ducts have air openings or perforations uniformly spaced over their surfaces. Tight wall ducts of metal or wood with one side open, and facing downward (inverted V or U) are also used as aeration ducts. The partial hopper aeration duct (Fig. 20) is used extensively in rice storages and has proven satisfactory.

Both axial flow (propeller) and radial flow (centrifugal) fans are used in aeration systems for stored rice. Generally propeller fans are used in flat storages and centrifugal fans in upright storages. However, either type may be used where the static pressure of the grain and the aeration system are not excessive for the fan selected.

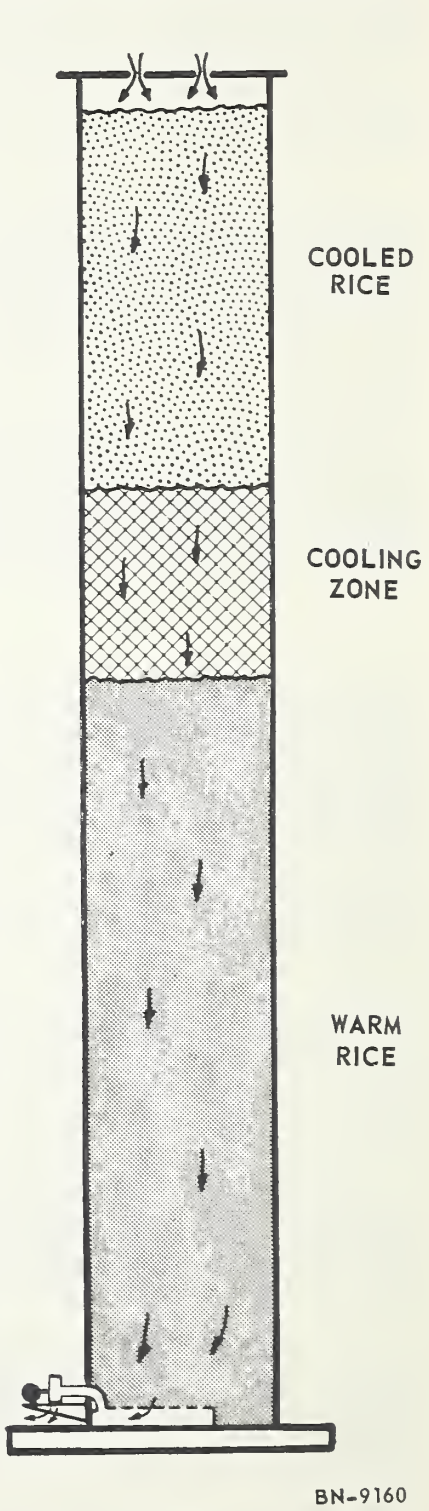

Figure 19.--Cooling zone in stored rice.

Three types of fan arrangements are common: (1) An individual fan for each storage or for each aeration duct, (2) one large fan connected to several storages or aeration ducts, and (3) a single portable fan that can be moved from storage to storage or from one aeration duct to another within a storage.

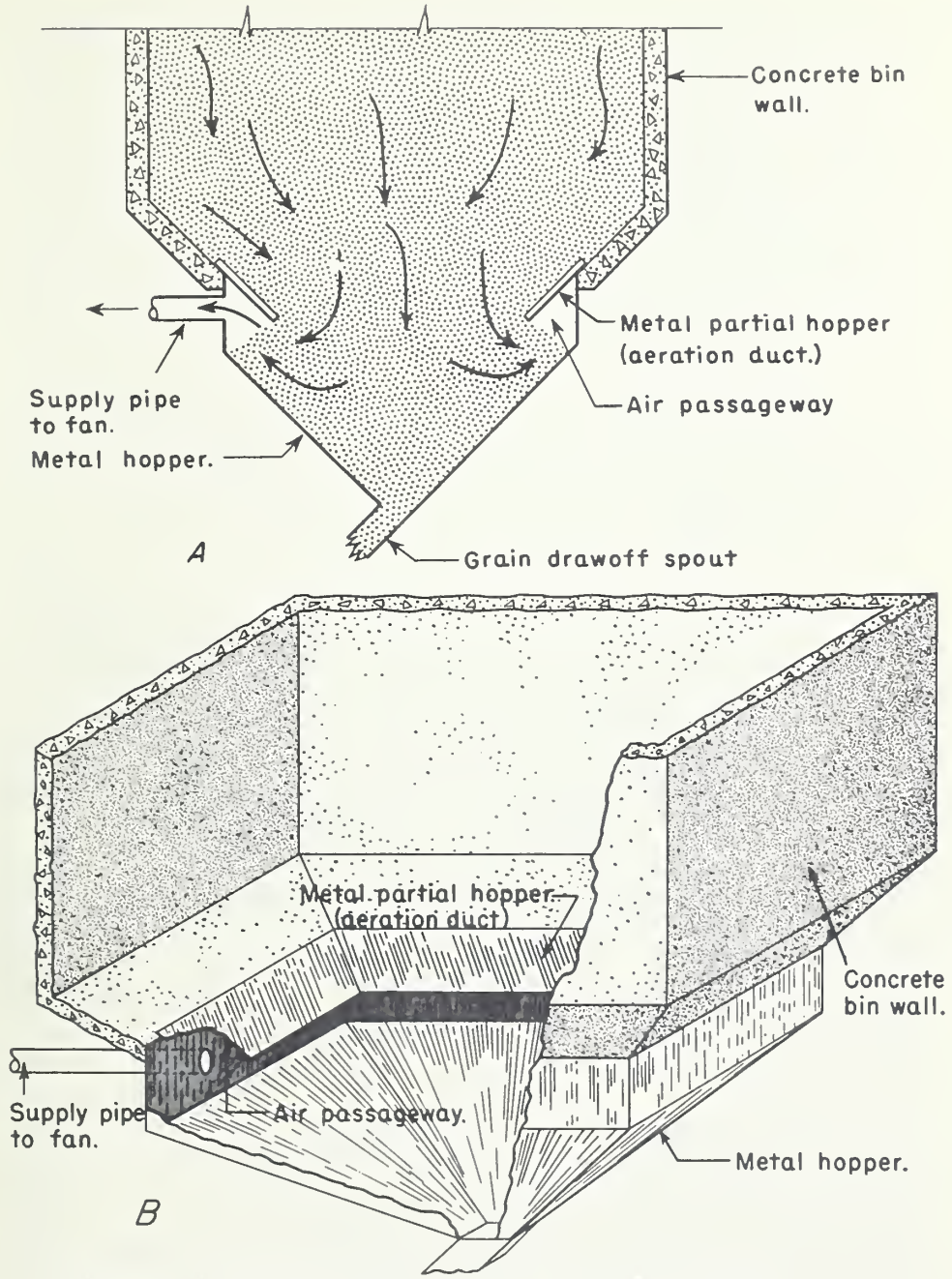

Figure 20.--Metal partial hopper installed in a rectangular upright storage to serve as an aeration duct: A, Section through lower part of storage showing grain in place around partial hopper and air passageway; B, cut-away view of lower part of storage showing arrangement of partial hopper. The performance of the partial hopper can be improved by perforating the hopper to provide additional duct surface area for the air to enter or leave the grain.

The size and type of fan and motor needed will be determined by the total air volume to be supplied and the static pressure against which the fan must operate. Figure 21 provides information for estimating the fan horsepower and static pressure requirements for aerating rice at different rates of airflow and at depths ranging from 10 to 150 feet. Static pressures were calculated from those reported by Shedd (58) for rough rice with a moisture content of 13 percent. To make allowances for packing of rice in storage and for pressure losses in the aeration system, Shedd's values have been increased 50 percent.

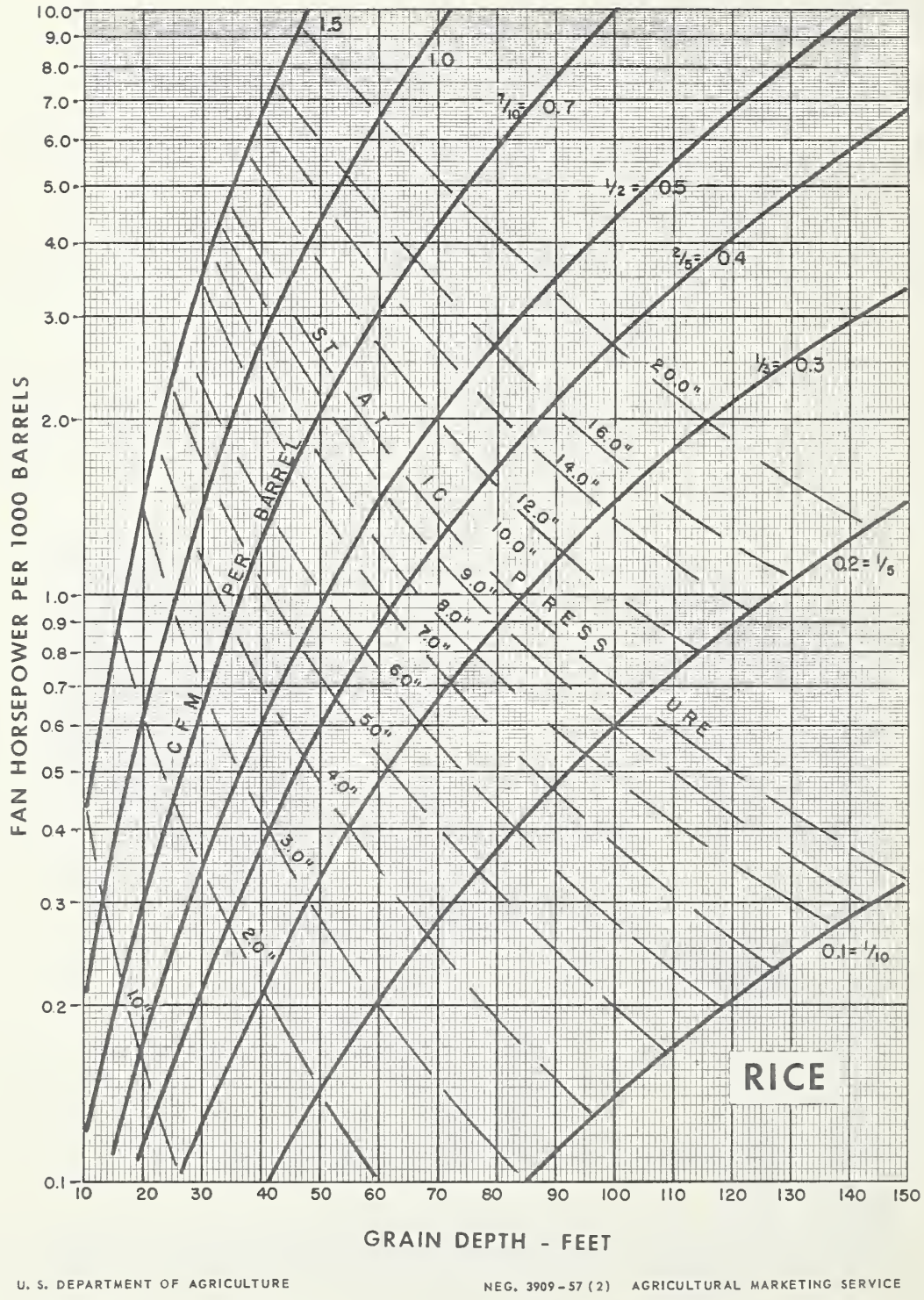

Figure 21.--Fan horsepower and static pressure (inches of water) requirements for aerating rice at different rates of airflow (cfm per bushel) and at grain depths ranging from 10 to 150 feet.

Aeration systems may be operated manually or by automatic controls. Manual operation requires close supervision since it is usually difficult to predict weather conditions. Automatic controls are desirable because (1) they can be set to operate fans at prescribed weather conditions, (2) they require only infrequent attention, and (3) they usually save enough in operating expense to justify their cost.

More information on the design, selection, and operation of aeration systems is given in Marketing Research Report 78 (67).

Storage in Sealed Bins

Rice direct from the combine was stored in hermetically sealed storage bins at Crowley, La., in the presence of CO_2 gas. Rice with a moisture content of 18 to 20 percent became sour after storage in the glass lined bins after test periods of 35 and 47 days, and after 7 months the CO_2 concentration was 21 percent (63, 64). Bacteria survived, molds markedly decreased, and yeasts proliferated in this type of storage where anaerobic conditions developed within a few days. Although this storage was not accompanied by heating there was loss of seed viability. The rice graded Sample because of the sour odor and discoloration of the kernels.

Milling quality of the rice was relatively good with turnouts being reduced from 81-111 to 66-111 lb./bbl. for the 7-month period and from 91-111 to 92-108 lb./bbl. for the 47-day period. After drying in an LSU continuous flow drier, the rice was sold through commercial channels, milled, and placed on the market with no sour odor. Other lots of rice with 21.5 to 32.4 percent moisture, stored in sealed containers in the laboratory, showed the same general changes except that the aerobic organisms often increased.

Storage of Parboiled Rices

Rice storage studies have also been conducted on long- and short-grain parboiled rice, both of which are important articles of commerce in the United States and other parts of the world (27, 28). Changes in the oil fraction of stored parboiled rice were followed as criteria of loss in quality. Storage of parboiled rice in the dark at several temperatures permitted a study of rancidification and of nonenzymatic changes in the oil as measured by peroxides, monocarbonyl compounds, and free acids. In open-container storage, values for peroxides, monocarbonyls, and free acids remained low during an induction period; then they rose markedly at or just before the time rancid odors appeared. Peroxides and monocarbonyls again decreased to low residual values and rancidity disappeared. Free acid values remained at the higher level. Original moisture contents of 11.4 to 12.5 percent fell to about 10 percent at 77° F., 6 percent at 100°, and 3 percent at 140°. Storage lives of two parboiled rices showed the same relative order at 77°, 100°, and 140°. Monocarbonyl maxima occurred in about 1 year at 77°, in 1 month at 140°, and in 1 week at 180°. In closed storage at 77° and 100° peroxide and monocarbonyl changes were similar to those for open storage, though induction periods were longer. At 140° no rise was shown. Free acidity increased linearly for considerable periods at all three temperatures. The rancidifying effect of light on fat containing foods was confirmed for parboiled rice during storage at 77°.

Color changes during storage of both Caloro (short-grain) and Century Patna (long-grain) parboiled rice were shown to be negligible for about 1 year at room temperature, 77° F., in either open or sealed containers. At 100° and 140° the changes appeared after 3 to 4 months, owing to nonenzymatic browning, accompanied by losses of reducing sugars, amino nitrogen, and free amino acids. Analyses were too insensitive to follow browning during storage. Sulfur dioxide added to the pearl (Caloro) rice during parboiling inhibited browning, and gradually disappeared during storage, but did not delay rancidification. Varietal and process effects were evaluated by accelerated storage tests at 140°. Moisture contents decreased from about 11 to 3.5 percent during 28 days of storage. Varietal differences had a minor effect on rancidification, but process differences greatly changed the keeping quality of a single variety.

Sack Storage

Practically all of the rough rice is stored in bulk. Sack storage is practical for relatively small lots and for storing seed rice.

A maximum moisture content of 14 percent is recommended to prevent loss in grade. For seed rice, moisture should be reduced to 12 percent or less.

PEST CONTROL IN STORED RICE

Insects

There is considerable information available on the insects that infest stored rice. In rough rice the lesser grain borer, the rice weevil, and the Angoumois grain moth compose a group that attacks sound kernels; their larvae live inside of the kernels. The grain and flour beetles attack broken kernels or kernels having damaged husks which allow the insects to reach the kernel. Included in this group are the cadelle, the saw-toothed grain beetle, the flat grain beetle, red flour beetle, and the confused flour beetle. Moths that infest the surface of bulk rough rice and of bagged rough rice and spin webbing in profusion include the Indian-meal moth, the almond moth, and the rice moth. In bran and milled rice, bran bugs become important and more of these species are troublesome. Included among the bran bugs are the flour beetles. The scientific names of the insects and detailed discussion of their habits are given in a recently revised USDA bulletin (69).

Insect infestation generally occurs after the rice is in storage. Surveys have shown that most rice harvested and dried by modern methods is relatively insect free upon entering storage. Well established insect control practices during the storage period are available and are generally applied in the United States. These include good housekeeping practices to suppress the sources of insects in and around farm bins, warehouses, and mills, and the fumigation of the rough or milled rice. Procedures and materials for use in controlling insect pests in stored rice are described in detail in a number of releases by the State agricultural experiment stations, State extension services, and the USDA (68).

Research on the occurrence and prevention of insects in stored rice is currently conducted by four agencies--the agricultural experiment stations of Arkansas, Louisiana, and Texas and the USDA Stored-Rice Insects Laboratory at Houston, Tex.

In Arkansas, a survey of farm-stored rice was carried out in Arkansas County during the storage seasons 1955-56 and 1956-57 to determine the source, incidence and severity of infestation, and influencing factors. Infestations in ripe rice standing in the field were found to be unimportant. However, the hairy fungus beetle was common in down rice. Freshly harvested rice being delivered from the field to commercial driers and dried rice leaving the driers were found to be infested with several species of stored-grain insects. The source of these was traced back to infestations in trucks and harvesting machinery. Stored-grain insects were commonly found in and around farm granaries before rice was stored in the bins. Roughly two-thirds of other farm buildings were infested with species which might migrate into the rice storage. When aeration was not employed, single-walled bins were much more frequently infested than double-walled bins, but there was little difference when aeration was used. Rice stored in the same granary with oats was more often infested than when stored separately. There was no consistent evidence that rice stored in bins previously used for oats was more likely to be infested than bins previously used only for rice. Fumigation of rice and oats as practiced on the farm was successful in about half the attempts observed. Low grain temperature probably was a contributing cause to failures. The effect of residual action following fumigation of rice was observed for approximately 10 days (56).

In Louisiana, studies are being directed toward protective treatments for farm stored rough rice. At Baton Rouge, 4 candidate treatments were applied to lots of rough rice at different application rates and the protection observed for a 2-year period. Nearly all of the infestation in the check bins and in the less successful applications was by the lesser grain borer. Damage by the rice weevil was nil, though chances for infestation were ideal. When lindane was absorbed in sawdust and mixed with the rice, the percentage of kernel damage after 12 months storage was 0.4, 1.0, 2.7, and 4.9 percent for dosage rates of 10, 5, 1, and 1/2 p.p.m. Residue analysis made after 24 months showed lindane residues ranging from 0.2 p.p.m. at the 1/2 p.p.m. application rate to 2.8 p.p.m. at the 5 p.p.m. rate. Pyrethrum protective sprays and dusts applied at a dosage rate of 1.1 p.p.m. of pyrethrins showed 7.5 and 6.9 percent damaged kernels, respectively. Malathion dusts at rates of 1 and 5 p.p.m. showed 9.7 and 11.3 percent damage after only 9 months and observations of this material were discontinued.

Methoxychlor dusts at 2 and 10 p.p.m. showed 13.6 percent damage after 9 months and 12.9 percent damage after 12 months, respectively. The check lot had 14.3 percent damage after 12 months.

Large-scale tests also were conducted at Crowley, La., with lindane and pyrethrum protective treatments. In May 1956 lindane impregnated sawdust was uniformly distributed throughout bulk rice at rates of 1 and 10 p.p.m. in one series of bins. In a second series a commercially available pyrethrum protective dust was applied at the dosage rate of 1.1 p.p.m. of pyrethrins. By August 15 the check bins were heavily infested and were fumigated. By March 1957 the bins treated with 1 p.p.m. of lindane in sawdust and those treated with 1.1 p.p.m. of pyrethrins were badly infested and were fumigated and terminated. The bins treated with 10 p.p.m. of lindane in sawdust remained in good condition throughout the remainder of the test period, until January 1958. It was concluded that lindane at 10 p.p.m. would protect farm-stored rice from insect infestation and damage for 2 years or longer. These results with lindane parallel other tests in which the material was applied to wheat and shelled corn at Manhattan, Kan., by the USDA Stored-Grain Insects Laboratory. However, lindane migrates by vapor action into the grain so that a substantial residue is present. At present there is no tolerance for residues of lindane on rice or on any other grain.

In Texas in December 1956 a survey was made of farm-stored rice in 10 rice growing counties in the Gulf Coast area. Of the 165 bins examined, 45 percent were found to be infested with one or more species of insects. The Indian meal moth and psocids were found with greatest frequency. Research has just been initiated directed toward the development of methods of applying malathion under the conditions encountered on the average rice farm. Rice of high moisture content is often placed in bins on the farm; subsequently the rice is dried in the same bins by moving large quantities of air through it, then left until the following spring. Under these conditions, the lethal effect of the protectant material added to the grain as the bin is filled must be capable of being maintained after the rice is subjected to the air drying process, or a method must be devised to apply the protectant after drying has been completed and without moving the rice. No findings are available as yet from these tests.

At Houston, an off-farm insect control research program is directed toward two objectives: (1) An improvement of fumigation procedures, and (2) the development of protective treatments for rough rice. The insect infestation problems encountered in the storage of CCC-owned rice are given special attention by this laboratory.

Nearly all studies on fumigation procedures involving both rough and milled rice are done under practical industry conditions, in cooperation with warehousemen storing mill-owned or CCC-owned rice, with fumigant manufacturers, and with dealers. The recirculation method of applying fumigants developed for the treatment of wheat and corn has been adapted to the fumigation of bulk rough rice. Existing aeration systems have been utilized by installing temporary return ducts from the fan to the headspace so that the fumigant can be drawn through the rice. A number of fumigations performed by warehousemen have been evaluated by making readings of the gas concentrations and exposing caged test insects at selected points. The recirculation method is now widely used in both upright and flat storages. These studies have been in cooperation with agricultural engineers.

A portable recirculation system that can be installed in already loaded freight cars has been adapted to the treatment of bulk rice in freight cars. This system consists of several probes with perforated tips which are inserted to the floor in a loaded freight car. The probes are connected to a manifold, which in turn is connected to a blower on the surface of the rice. The gas is drawn down through the rice when the blower is operated, then up through the probes and discharged into the headspace.

The method adopted by the USDA Commodity Stabilization Service of fumigating bagged milled rice under tarpaulins was evaluated at all stages of the recent storage program. When it became advisable to discontinue fumigation with methyl bromide because of the probability of exceeding the tolerance for residues of inorganic bromide,

the personnel at the USDA Houston laboratory helped in the switch to HCN (hydrocyanic acid) fumigation. Adequate dosage rates of HCN were developed. When it became apparent that there was considerable retention of HCN following a fumigation, this condition was measured, and subsequent fumigation rates reduced by this amount. With the change in CSS practices from storing milled rice to storing bulk rough rice, dosage rates for HCN applied by recirculation were developed.

Fumigation of warehouses full of bagged milled rice was done by sealing the warehouse and treating it as one unit. This fumigation was evaluated under a number of circumstances so that adequate dosage rates of both methyl bromide and HCN were developed.

The studies directed toward developing protective treatments for rough rice were likewise done under commercial storage conditions. Carload lots of rice have been treated as they were being bagged for warehouse storage. Applications of ryania dust composed of ground stems of Ryania gave excellent protection against infestation for periods of 1 to 2 years, but the tests were discontinued because of the improbability of residue tolerances being established. Pyrethrum treatments gave erratic results, probably because the application rates were too low for the conditions prevalent in rice storage. A few tests with considerably higher rates gave almost perfect protection. The cost of an effective treatment with pyrethrum may be uneconomical.

Further tests with bagged rough rice were abandoned, since the trend in industry is for bulk storage. A test was begun in the spring of 1958 to evaluate malathion as a protective treatment for bulk-stored rice. A tolerance for residues of this insecticide on grains, including rice, was established in 1957. Tests with wheat and shelled corn indicate that malathion is potentially a very good protective treatment within the limits of the established tolerance. Therefore the prospects of accomplishing the objective of this line of study are excellent.

The rice industry stands on the threshold of important developments in relation to preventing insect infestation in rough and milled rice. A vigorous research effort will bring about the realization of the excellent prospects currently in view. The following areas of research are needed to culminate the recent string of advances:

a. Further improvement of fumigation procedures. The long-used procedures in fumigation have been abruptly redirected with the advent of the recirculation method of application and the new problem of undesirable residues of inorganic bromide resulting from successive fumigations with methyl bromide or mixtures containing ethylene dibromide. Further complications are the change from bag to bulk storage of both rough and milled rice and the trend toward more and longer storage of the commodity as rough rice instead of milled rice. Further research is needed to develop procedures to meet all of the situations engendered by these changes so freedom from violating residue tolerances will be assured.

b. Further development of protective treatments. An effective and inexpensive protective treatment appears to have a great potential value to the rice industry. Vigorous and immediate research is needed to determine whether malathion will meet all of the requirements and, if it does, to develop the procedures for its use under the various storage and handling conditions of the industry. Concurrently with these studies, alternate materials should be evaluated and the procedures developed for the use of one or more of them to meet any inadequacies of the malathion treatments as found under certain conditions.

c. A study of the relationship of infestation in rough rice to the yield and quality of milled rice under the environmental conditions of modern storage practices. Most of the studies related to the infestation and damage of stored rice were done years ago, before the days of combining, hot air drying, aeration, and bulk storage. The same insect species are present, but it has been observed that their relative importance has changed. An intensive study is needed to reestablish a thorough understanding of the importance of the damage done by each species. This will in turn pinpoint control measures and reduce

their cost. Furthermore, actual damage is almost a secondary consideration in this age. The potential of a given species, or the control measures applied to it, of contaminating the finished product with either insect fragments or undesirable insecticidal residues is probably more critical. A sound knowledge of the habits of the species in relation to these factors is essential in developing an economical and effective program to prevent insect infestation.

Rodents

Rats commonly infest rice storages in the Gulf Coast area, but mice are not common. Rats can consume considerable quantities of rice and cause severe financial losses. They also can contaminate either rough or milled rice, and make either type unfit for human consumption as determined by the inspectors of the United States Food and Drug Administration. In some areas storage buildings are made ratproof, but such endeavors in commercial rice storages have not been very successful. The usual practice is to rely on trapping and baiting.

Only anticoagulants and Red Squill[18] are permissible to use around a rice storage, since a food material is involved and materials poisonous to humans are prohibited. There are four types of anticoagulants--Warfarin, Pival, Diphacinone, and Fumarin.[18] The first three come in water soluble form, so can be used in water as well as in baits. The last material is not yet available as a water soluble salt. The Fish and Wildlife Service of the U.S. Department of the Interior, Washington 25, D.C., has developed standard and detailed procedures to follow in baiting for rats. Such information will be readily supplied.

Birds

Birds are of concern because of the possibility of contamination of rice with their droppings if they are present in warehouses. The usual method is to screen all points where birds can normally enter a warehouse and thus exclude them. Information on this pest may be obtained from the Fish and Wildlife Service, U.S. Department of the Interior.

ECONOMIC CONSIDERATIONS IN DRYING AND STORAGE OF RICE

An essential adjunct of the development of new and improved techniques for the performance of any function is an economic appraisal of the comparative cost and efficiency of the applications. The final decision as to whether a new approach may be justified also must consider the effect on the quality of the product. Often refinements developed through research cannot be wholly utilized because the additional revenue obtained is insufficient to offset the costs of adopting the process. However, unless an adequate economic appraisal is made, research findings either may be disregarded or blindly followed without a sound basis for the decision.

A minimum of attention has been given to the economics of drying and storage of rice. Such studies as have been undertaken have tended to be of a limited nature and have not fully answered many of the problems involved in establishing the most profitable combination of factors which will maintain the quality of rice during the conditioning process and storage period. In recent years, work has been carried on in Arkansas, Louisiana, Texas, and California. Currently the Arkansas Agricultural Experiment Station is carrying on an analysis to determine the effects on quality as measured by milling and head rice yield under a variety of drying and storage conditions on farms. Attention is being directed toward changes in rough rice during the storage period associated with method of drying; type of storage structure; type and variety of rice; temperature fluctuations during storage; variations in moisture content of the rice; and use of alternative practices for controlling insects, rodents, and fungi. A broader and more general study was made in Louisiana by Efferson, Hathorn, and Gerlow (10) during 1951 and 1952--to appraise by type and

[18] Mention of products does not constitute endorsement by the U.S. Department of Agriculture over other products not mentioned.

ownership the storage facilities for rough rice then existing in the southern rice area in relation to current and future storage needs; to determine the costs of storage of rough rice under the various types of units used and methods employed; and to evaluate problems involved in storing rough rice for commercial use and for seed. Both commercial and on-farm storage units were included in the study. Wide variations were found in availability and adequacy of storage structure, practices employed, costs of performing the storage function, and quality of product. The changes in methods and facilities since the study was made, the relatively short period of time for the study, and the small sample covered by the survey make the findings valuable chiefly as a base point for reference in future analyses.

During 1954 and 1955 two economic studies were made by the Texas Agricultural Experiment Station. Hildreth and Sorenson (19) sought an answer to the problem of maximizing producers' income by consideration of the alternatives available to them, i.e. sale of rice immediately after harvest; drying and holding the rice on the farm for later sale after the flush marketing period; and drying and storing in commercial facilities while retaining title to the rice for future sale. Overhead and operating costs as well as quality of product measured in terms of milling yield were determined for on-farm operations. Prevailing commercial charges for the services were compared in arriving at producers' returns. Seasonal fluctuations in market price for rice during the marketing year also were taken into account. Although the Louisiana study indicated that large operators could dry and store rough rice as cheaply on the farm as off it, the Texas analysis did not directly compare the feasibility of performing these functions on and off the farm. As both of these investigations were based on limited samples, used different approaches during different storage seasons, and covered different areas, direct comparison of the findings is not feasible. A more comprehensive analysis is required before definitive conclusions can be reached. The Louisiana Agricultural Experiment Station in conjunction with the U.S. Department of Agriculture Farmer Cooperative Service currently is studying commercial and farm drying and storage in the southern area in an effort to shed additional light on the question of where the drying and storage functions may most economically be performed.

Moore and Whitney (53), also of the Texas station, appraised the factors relating to the optimum time for selling rice during the marketing year. The study was made to determine whether seasonal behavior of the market price for rice provided farmers a profit from storing rice in commercial elevators and selling it later rather than at harvesttime. Investigations were made of the seasonal movement of the farm price of rice, of the cost to farmers of holding rice in commercial storage facilities, of the relationship between the seasonal movement of price and the cost of commercial storage, and of other pertinent conditions. The going rate of commercial charges for drying and storage was used in the analysis. No attempt was made to develop actual costs of commercial operations.

In California, studies have been made on the relationships between drying conditions and drying costs in commercial driers (74).

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APPENDIX A

LIST OF CONTRIBUTORS

Agricultural Experiment Stations

Arkansas

R. L. Beacher	Agronomy
Xzin McNeal	Agricultural Engineering
W. R. Morrison	Agricultural Economics
L. H. Rolston	Entomology
F. J. Williams	Agronomy

California

D. C. Finfrock	Agronomy
S. M. Henderson	Agricultural Engineering

Louisiana

H. T. Barr	Agricultural Engineering
C. N. Bollich	Agronomy
J. R. Campbell	Agricultural Economics
E. H. Floyd	Entomology
A. T. Harrell	Agronomy
R. P. Walker	Agricultural Engineering
V. R. Williams	Biochemistry
F. T. Wratten	Agricultural Engineering

Texas

C. C. Bowling	Entomology
L. E. Crane	Agronomy
N. S. Evatt	Agronomy
R. J. Hildreth	Agricultural Economics
C. A. Moore	Agricultural Economics
J. W. Sorenson, Jr.	Agricultural Engineering

United States Department of Agriculture

Agricultural Research Service

C. R. Adair	Crops Research
W. C. Dachtler	Research Coordinator
E. H. Dawson	Human Nutrition Research
J. V. Halick	Crops Research
J. T. Hogan	Southern Utilization Research
D. F. Houston	Western Utilization Research
W. V. Hukill	Agricultural Engineering Research
E. B. Kester	Western Utilization Research
M. M. MacMasters	Northern Utilization Research
T. Wasserman	Western Utilization Research

Agricultural Marketing Service

L. E. Holman	Marketing Research
R. S. Hutchison	Marketing Research
H. A. Kramer	Marketing Research
R. Latta	Marketing Research

Farmer Cooperative Service

J. K. Savage	Marketing Division